IDEAS Work Package 3
Evaluation of incorporation cases

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RT/2004/2/ION

Febbraio 2004
Abstract
The IDEAS project for the development of “General guidelines for the estimation of committed dose from incorporation monitoring data” (EU contract FIKR-CT2001-00160) is divided in 5 Work Packages (WP). At the moment 3 of them have been concluded.
In the WP1 the Internal Contamination Database has been set up, collating descriptions of case scenarios and the follow up measurements of incidental cases found in the open literature or in other reports, judged to be interesting for internal dose assessment.
In WP2 the IMIE code (developed by Radiation Protection Institute of Ukraine) has been improved and fitted to the special requirements of the IDEAS project.
In WP3 many case studies have been evaluated by contractors using reference software, the evaluations were collated and an Evaluation of Cases Database has been set up. It contains a summary of information for 95 evaluations on 52 cases (17 radioisotopes) permitting the comparison of different approaches to evaluation on the same case scenario, and providing links to the IDEAS Internal Contamination Database, were the original monitoring data can be found. From the database it is also possible to open the file describing each evaluation where detailed information on each contractor’s approach, assumed hypotheses and parameters can be found. The selection of cases to be evaluated was made on the basis of the radioisotope or mixture present in the case scenario, complexity present in the data set (e.g. multiple types of monitoring data) and special issues to be considered in the guidelines.
In the present report the results of WP3 are described.
Firstly, items related to the monitoring data are treated: conversion, uncertainty, presence of early data, grouping of data, criteria for exclusion, and method of interpretation.
Secondly, the parameters involved in the assessment are reviewed and effects on the evaluations are presented: time pattern of intake, pathway of intake, absorption type, AMAD, f1 value, subject related systemic retention parameters.
Thirdly, special aspects are considered: handling of data below limit of detection, use of excretion data altered by DTPA treatment, modelling of internal 241Am ingrowth in time due to 239Pu intake, wound intake modelling.
Fourthly the comparison of estimations presenting committed effective doses below the so called “interpretation level” (1 mSv) between reference and best-estimate approaches are presented.
Finally, the indications supporting the development of general internal dose assessment guidelines are reported.

Riassunto
Il progetto IDEAS per lo sviluppo di “Linee guida generali per la stima della dose impegnata dai dati di monitoraggio della incorporazione” (contratto EU FIKR-CT2001-00160) è articolato in 5 moduli (Work Package WP). Al momento 3 di essi sono giunti a conclusione.
Nel Work Package 1 (WP1) è stato realizzato un Internal Contamination Database raccogliendo le descrizioni di scenari di contaminazione con le relative misure di follow-up recuperati dalla letteratura, da altri rapporti e giudicati sufficientemente interessanti per la valutazione di dose interna.
Nel WP2 il codici di calcolo IMIE (sviluppato dal Radiation Protection Institute ucraino) è stato migliorato ed adattato alle esigenze del progetto IDEAS.
Nel WP3 molti casi di studio sono stati valutati dai diversi contraenti usando due software di riferimento; le valutazioni sono state raccolte ed è stato realizzato un database denominato Evaluation of Cases. Esso contiene il riassunto delle informazioni relative a 95 valutazioni su 52 casi (17 radioisotopi) permettendo la comparazione di differenti approcci alla valutazione di dose, per lo stesso scenario di contaminazione e fornendo il collegamento all’Internal Contamination Database, dove possono essere reperiti i dati originari di monitoraggio.
Dal Evaluation of Cases Database è anche possibile aprire i documenti che descrivono nel dettaglio ogni valutazione che presentano l’approccio del contraente, le ipotesi assunte ed i parametri usati.
La selezione dei casi che dovevano essere valutati era stata effettuata sulla base dei radioisotopi coinvolti o della miscela presente nello scenario, della complessità presente nell’insieme dei dati (tipologie dei dati di monitoraggio) o di argomenti speciali che devono essere considerati nelle linee guida.

**Keywords**
Internal dose assessment, Evaluations, Fitting procedures, Guidelines.
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Annex 1: List of evaluators, affiliation and code used throughout the document

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Executive summary

The 3rd European Intercomparison Exercise on Internal Dose Assessment carried out in the framework of the EULEP/EURADOS/UIR concerted action “Environmental and occupational dosimetry: An integrated approach to radiation protection covering radioecology, dosimetry and biological effects” gave special consideration to the effects of the new models and the choice of input parameters on the assessment of internal doses from monitoring results. The most important conclusion of the exercise, also indicated in the final workshop in Weimar in May 1999, was the need to develop agreed guidelines for internal dose evaluation procedures in order to promote harmonisation of assessments between organisations and countries, which has basic importance in EU countries.

The IDEAS project for the development of “General guidelines for the estimation of committed dose from incorporation monitoring data” (EU contract FIKR-CT2001-00160) has the aim of optimising the procedures for assessing internal doses from the results of monitoring. This is being achieved by collecting incorporation cases (Work Package, WP, 1), preparing evaluation software (WP2), developing general guidelines (WP4), and testing them in a practical way (WP5) by means of a 4th intercomparison exercise.

The scope of WP3 of the IDEAS project is to provide an agreed strategy for the development of general guidelines for internal dose assessment, based on the experience of evaluating a wide range of cases.

To support the development of the guidelines, which will be issued in the next WP (WP4), a total of 68 cases was chosen for evaluation. In WP3 the evaluations have been carried out and collected, a database has been set up (Evaluation of Cases Database) and issues to be introduced in the summary report have been extensively discussed between the contractors. Fifty-two of the 68 selected cases have been evaluated, 29 of them by two or more evaluators. For some cases the same evaluator provided more evaluations related to different radioisotopes. Each evaluator provided a MS Word file related to case, evaluator and radioisotope involved.

An Evaluation of Cases Database (DB) has been set up with a summary of information about each evaluation. Using the DB it is possible to compare different approaches to evaluation on the same case scenario and also open the IDEAS Internal Contamination Database were the original monitoring data can be found. From the database it is also possible to open the document file describing each evaluation, where detailed information on the assessor’s approach, assumed hypotheses and parameters can be found.
In each evaluation the assessor was asked to point out the issues that can be useful for developing the guidelines. The responsibility of the leader of WP3 was to collate the evaluations and find a common strategy to be applied in general guidelines.

For each case the following steps are performed:
- Collation of information coming from the evaluations and input into the Evaluation of Cases Database using proper record format.
- Identification of choices performed by contractors in absence of specific information.
- Presentation of effects of different assumptions on intake and committed effective dose estimated values.

The list of items on which to focus attention was agreed at the Bologna Contractors meeting (June 2003) and was divided into 3 main parts.

- Items related to the monitoring data: conversion of units, uncertainty, presence of early data, grouping of data, criteria for exclusion and method of interpretation, best monitoring type to use in evaluations.
- Items related to parameters involved in the assessment: time pattern of intake, pathway of intake, absorption type, activity median aerodynamic diameter, f1 value, subject related systemic retention parameters.
- Items related to special aspects: handling of data below the limit of detection (<LOD), use of excretion data altered by DTPA treatment, modelling of internal $^{241}\text{Am}$ ingrowth over time due to previous $^{241}\text{Pu}$ intake, wound intake modelling.

On the basis of discussions at the Bologna Contractors meeting the comparison of estimations presenting committed effective doses below the so-called “interpretation level” (1 mSv) between reference and best-estimation approach has been also done.

The detailed indications related to the main suggestions for the guidelines have been reported in the conclusions of this report. It is important to note here that the experience gained on the 52 cases provides sufficient arguments to support most of the advice indicated in the conclusions. So the majority of items related to data and parameters have been thoroughly considered. Considerable experience has also been collected in the treatment of the <LOD data to support a choice of replacing them with values of half LOD.

However, the authors note that more effort is needed for some special aspects due to the limited experience gained during the course of WP3, in particular for issues related to americium ingrowth, modelling of absorption after intake by wounds, and modelling of the increase in urine excretion after DTPA treatment.
Chapter 1

Introduction

The overall objective of the project IDEAS (EU Contract No. FIKR-CT2001-00160) is to develop guidelines for standardized assessments of internal doses to be made from monitoring data: measurements of radioactivity in a worker’s organs or whole body, or excreted activity in urine and/or feces. Assessments of committed doses from such data require application of a model and estimates or assumptions to be made about factors such as the time course of exposure, and the physical and chemical form of the material. Specific objectives of the project are:

- To enable dosimetry services across Europe to assess the same radiation dose from any given set of monitoring data.
- To reduce uncertainties and improve confidence in internal dose assessments.
- To reduce the effort involved in making internal dose assessments, and hence their cost to industry.

The project therefore contributes directly to the objectives of the Fifth EU Framework Program: to improve the monitoring and assessment of exposures to radiation in the workplace, thereby providing better protection and use of human resources.

The project is divided into Work Packages (WP), one for each of the five major tasks. The structure of the project and the interaction between Work Packages are shown in Figure 1.1.

Work Package 1 entitled Collection of incorporation cases was devoted to the collection of data by means of bibliographic research (survey of the open literature), contacting and collecting data from specific organisations and using information from existing databases on incorporation cases. Two databases (the IDEAS Bibliography Database and the IDEAS Internal Contamination Database) were prepared and some reference cases for the performance of WP 3 selected.

In Work Package 2 (Preparation of evaluation software) an existing computer code IMIE [1] was to be used as a platform for testing existing methods and approaches for bioassay data interpretation and methods developed in the project. This software was to be provided to the partners for the evaluation of reference cases. In this WP, different and new methods of data interpretation were studied and compared, the pilot program unit of IMIE was developed and tested, and the procedures of input and output data from the IDEAS Internal Contamination Database (WP1) implemented.

Work Package 3 deals with the Evaluation of incorporation cases using the reference cases from WP1 and evaluating them by means of the IMIE software provided by WP2. The current version of another computer code IMBA [2] was also made available to the participants to support the evaluation procedures. Selected cases were to be evaluated by at least two partners. The evaluations were compiled in a database, pointing out common assumptions for similar scenarios, applied models and parameters and procedures to assess uncertainties, handling outlying data and measurements below the limit of detection etc.

In Work Package 4, which is the core of the project (Development of the general guidelines), the partners will derive a common strategy for the evaluation of monitoring data, draft the general guidelines and discuss it with internal dosimetry experts by means of a “virtual” workshop based on the Internet. The discussion will improve the common strategy and permit finalisation of the draft of the general guidelines.

In Work Package 5 (Practical testing of general guidelines) the validity of the draft guidelines will 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). The intercomparison will be prepared; all the participants will receive the guidelines and will be invited to use them during the assessment of incorporation cases. The organisation of a Workshop (open to all the intercomparison participants), for discussing the results
and finalising the report of the intercomparison is also scheduled. The last step of WP5 is the publication of the final version of the general guidelines and their submission to national and international bodies for approval.

Figure 1.1: Structure of Work Packages in IDEAS Project

As the project is in progress its status can be summarized as follows.

Within WP1 two databases have been set up. The first is the so-called IDEAS Bibliography Database, which collects information present in the open literature or in other reports dealing with internal contamination cases. All the participants in the project were involved in obtaining data from these and other sources of information. The structure of the database permits the user to view the database, search it and input new data. More than 500 references have been collected. The references were distributed among the participants for reviewing and commenting on the papers from the point of view of their suitability for internal dose assessment (well documented cases). The selected case descriptions constituted the basis of another database called IDEAS Internal Contamination Database. Besides the use of the databases for the purpose of the IDEAS project, they also provide useful tools for the scientific community interested in internal dosimetry for studying internal contamination cases. They have been put in a restricted web page presently available to the IDEAS partners only, but will be made accessible to everybody in the near future.

The second database is the above mentioned IDEAS Internal Contamination Database. This database has been set up to collate, in a given format, the descriptions of the selected well documented cases (contamination scenarios and follow up measurements). This means that the structure of the IDEAS Internal Contamination Database permits the collection of all the information needed for internal dose assessment i.e. the description of the working area and characteristics of the work, date and modalities of the initiating event, actions taken, physical and chemical characteristics of the contaminant, etc. For each contamination case, the participating partners entered the available information and monitoring data into a structured spreadsheet file for transfer into the database. Currently this database contains more than 200 cases.
The IMIE (Individual Monitoring of the Internal Exposure) computer code was chosen for evaluation of the selected reference case studies. IMIE was developed for the purposes of retrospective dosimetry. It gives to the dosimetrist a very good tool for the analysis and interpretation of multiple bioassay measurements. IMIE helps the assessor to make estimations about the history of intakes and corresponding doses on the basis of individual monitoring data. In particular it permits the user to review and compare the possible variants of exposure condition combinations and to select the degree of automation from fully automated to completely manual regimes. Within WP2 the IMIE code has been improved and fitted to the special requirements of the IDEAS project. For instance during the course of WP2 a new optimisation algorithm of numerical deconvolution of monitoring data has been developed and a new probabilistic algorithm based on statistical methods has also been introduced. The final aim of WP2 has thus been achieved, namely to provide the participants a useful and flexible tool for the dose evaluation process of WP3.

The choice of cases to be evaluated was made on the basis of the characteristics of the radioisotope or mixture present in the case scenario, the complexity present in the monitoring data set (e.g. multiple types of monitoring data) and special issues to be considered in the guidelines. The evaluation and analysis of selected cases was carried out in accordance with the scheduled work program of WP3. For this purpose 68 cases covering different circumstances and 17 radionuclides were selected from the IDEAS Internal Contamination Database and distributed among the partners for detailed evaluation. Fifty-two of the 68 selected chosen cases have been evaluated, 29 of them by two or more assessors. For some cases the same assessor provided additional evaluations related to different radioisotopes. The selected cases were evaluated using the IMIE and IMBA Expert™ codes using different assumptions and making relevant comments. The best estimates of the calculated intake and committed effective dose were given in each case, together with notes on important issues related to the guidelines. The results were presented as Microsoft® Word documents and in condensed version in Microsoft® Excel files in a fixed format and were collected in the Evaluation of Cases Database established for this purpose. Ninety-five independent evaluations on 52 cases have been collected in the database. The Evaluation of Cases Database provides possibilities, among others, to view the results of evaluations, to search within the database according to different aspects, to compare different evaluations on the same case and has links to the IDEAS Internal Contamination Database.
Chapter 2

The choice of cases, their evaluation and the Evaluation of Cases Database

2.1 Introduction
The selection of cases to be evaluated was made on the basis of the radioisotope or mixture present in the case scenario, complexity present in the data set (e.g. multiple types of monitoring data) and special issues to be considered in the guidelines.
The selection was performed during the Oxford meeting in September 2002. At that time only 106 cases were available in the IDEAS Internal Contamination Database and a search on radioisotopes enabled the choice of radioisotopes that were of interest to the various contractors.
The cases were distributed to two contractors each, on the basis of interest in the elements. For two assessments on each of the 67 selected cases, this meant an average of about 17 for each contractor. The original table with the chosen cases is reported in Table 2.1. One more case (no. 206) has been added during the performance of WP3.

2.2 Number of evaluated cases
In Table 2.1 the radionuclide and the number of the cases related to that radionuclide are reported. In the table also the number of cases having 1 or 2 evaluations has been reported.
Due to problems related to the time schedule of WP3 not all the chosen cases have been evaluated by the contractors and some of them have only one evaluation performed.
In total 94 evaluations on 51 cases (out of 67 initially chosen) with 17 radionuclides were performed. One more case (no. 206) is added later during the performance of WP3. As final figures 95 evaluations on 52 cases were performed (68 chosen) with 29 of them having 2 or more evaluations.

Table 2.1: Chosen cases to be evaluated for the radionuclide or element involved, case number, contractors in charge of the evaluation of the case. The cases reported in bold have 1 evaluation, cases reported in bold and italics have 2 or more evaluations.

<table>
<thead>
<tr>
<th>Radionuclide or Element</th>
<th>Case Numbers</th>
<th>Number of chosen cases</th>
<th>Number of cases with 1 evaluation</th>
<th>Number of cases with 2 evaluations</th>
<th>Contractor in charge 1</th>
<th>Contractor in charge 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{125}$I</td>
<td>8, 27, 28, 60, 62, 66, 106</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>KFKI</td>
<td>IRSN</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>18, 19, 20, 21, 25, 92</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>KFKI</td>
<td>RPI</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>KFKI</td>
<td>IRSN</td>
</tr>
<tr>
<td>$^{89}$Sr</td>
<td>48, 49, 65</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>SCK</td>
<td>ENEA</td>
</tr>
<tr>
<td>$^{90}$Sr</td>
<td>7, 26, 1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>FZK</td>
<td>ENEA</td>
</tr>
<tr>
<td>$^{202}$Tl</td>
<td>64</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>ENEA</td>
<td>FZK</td>
</tr>
<tr>
<td>$^{95}$Zr</td>
<td>75</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>ENEA</td>
<td>EDF</td>
</tr>
<tr>
<td>$^{32}$P</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>ENEA</td>
<td>FZK</td>
</tr>
<tr>
<td>$^{192}$Ir</td>
<td>29</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>NRPB</td>
<td>KFKI</td>
</tr>
<tr>
<td>$^{210}$Po</td>
<td>46</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>ENEA</td>
<td>SCK</td>
</tr>
<tr>
<td>$^{3}$H</td>
<td>6, 22, 23, 63</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>EDF</td>
<td>NRPB</td>
</tr>
<tr>
<td>$^{241}$Am</td>
<td>17, 32, 77, 206</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>RPI</td>
<td>FZK</td>
</tr>
<tr>
<td>Pu (wound)</td>
<td>3, 33, 34, 41, 42, 45</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>FZK</td>
<td>EDF</td>
</tr>
<tr>
<td>Pu (inh)$^2$</td>
<td>14, 15, 16, 39, 40, 43, 44, 47</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>SCK</td>
<td>NRPB</td>
</tr>
</tbody>
</table>

$^1$ Evaluated by NRPB  
$^2$ Only Pu-cases without isotopic specification.
In Table 2.2 details of all the evaluations are reported. As can be seen in cases 1, 13, 14, 15, 16, 30, 31, 47 and 91 there are additional evaluations for different radionuclides performed by the same contractor alone or in connection to the other evaluator that sometimes performs only one evaluation (cases 15, 16, 47 and 91). In case 13 all the three U isotopes (\(^{234}\)U, \(^{235}\)U, \(^{238}\)U) have been all evaluated by both contractor in charge. In another cases (14) two radioisotopes (not always the same) have been evaluated for the same case due to the presence of a mixture. In this case it is not possible to compare the same radioisotopes as evaluator E2 evaluated \(^{239}\)Pu and \(^{241}\)Am instead of evaluator E4 which evaluated \(^{238}\)Pu and \(^{239}\)Pu.

**Table 2.2:** Indication of evaluations and brief description of cases (cases with 2 or more evaluators are reported in shadow)

<table>
<thead>
<tr>
<th>Case Number</th>
<th>Number of evaluations</th>
<th>Typology of case and brief description.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2 (1 evaluator for 2 isotopes)</td>
<td>Incident with graphite powder and fission products. (^{137})Cs, (^{90})Sr data from an incident in the preparation of fuel elements. Urine and feces data for (^{90})Sr and WBC measurements for (^{137})Cs are available.</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Overdose: accidental injection of (^{32})P. Urine data available.</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>Chronic exposure to (^{239})Pu for over 10 years. Urine data available. Large number of (&lt;\text{LOD} \text{ data}.</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>Chronic exposure to (^{3})H from wristwatch (volunteer). Urine data available.</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>Acute intake of (^{90})Sr by a woman. Urine data available.</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>Chronic exposure to (^{137})Cs by ingestion after Chernobyl accident. WBC measurements available.</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>Accidental inhalation of (^{239})Pu due to explosion in glove box. Urine and feces data available. One urine (&lt;\text{LOD} \text{ data.}</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>Reconstruction of an old exposure to mixture of Pu isotopes. Many (&lt;\text{LOD} \text{ data.} Urine, feces, lung, liver and skeleton data available. Ingrowth of (^{241})Am from (^{239})Pu to evaluate (^{239+240})Pu values using known isotopic ratios.</td>
</tr>
<tr>
<td>13</td>
<td>6 (2 evaluators, 3 isotopes each)</td>
<td>Chronic enriched U inhalation. Urine data available.</td>
</tr>
<tr>
<td>14</td>
<td>4 (2 evaluators, 2 isotopes each)</td>
<td>Acute exposure to Pu isotopes as nitrate. Urine and teeth measurements available. Limited use of DTPA (2 days). Ingrowth of (^{241})Am from (^{241})Pu. No initial (^{241})Am is present.</td>
</tr>
<tr>
<td>15</td>
<td>3 (2 evaluators, one for 2 isotopes)</td>
<td>Acute exposure to Pu isotopes as nitrate. No initial Am. Urine data available. Same case scenario as case 14. Limited use of DTPA (2 days).</td>
</tr>
<tr>
<td>16</td>
<td>3 (2 evaluators, one for 2 isotopes)</td>
<td>Acute exposure to Pu isotopes as nitrate. No initial Am. Urine data available. Same case scenario as case 14. Limited use of DTPA (1 day).</td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>Acute exposure to (^{60})Co in a facility for preparing (^{60})Co sources. WBC measurements available.</td>
</tr>
<tr>
<td>Case</td>
<td>Evaluators</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>19</td>
<td>2</td>
<td>Acute exposure to $^{60}$Co. WBC measurements available. Same case scenario as case 18.</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>Acute exposure to $^{60}$Co. WBC measurements available. Same case scenario as case 18.</td>
</tr>
<tr>
<td>21</td>
<td>2</td>
<td>Acute exposure to $^{60}$Co. WBC measurements available. Same case scenario as case 18.</td>
</tr>
<tr>
<td>22</td>
<td>1</td>
<td>Routine measurements of $^3$H. Urine data available.</td>
</tr>
<tr>
<td>23</td>
<td>2</td>
<td>Acute exposure to $^3$H as gas after sealing an ampoule. Urine data available.</td>
</tr>
<tr>
<td>24</td>
<td>2</td>
<td>Acute exposure to $^{60}$Co. WBC measurements available. Same case scenario as case 18.</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>Acute exposure to $^{90}$Sr. Urine, feces and WBC data available.</td>
</tr>
<tr>
<td>26</td>
<td>1</td>
<td>Repeated intakes of $^{125}$I. Thyroid measurements available. Routine monitoring.</td>
</tr>
<tr>
<td>27</td>
<td>2</td>
<td>Repeated intakes of $^{125}$I. Thyroid measurements available. Routine monitoring.</td>
</tr>
<tr>
<td>28</td>
<td>1</td>
<td>Acute inhalation of $^{192}$Ir in a laboratory for encapsulation of radioactive gamma sources. The worker sharpened the wolfram electrode by grinding it without checking its possible contamination. WBC measurements available.</td>
</tr>
<tr>
<td>29</td>
<td>2</td>
<td>Unknown intake(s) of $^{239}$Pu and/or $^{239}$Pu. Same subject involved in two factories: Pu processing facility and Pu research laboratory. Urine data available during 13 years. Some &lt;LOD data.</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>Acute exposure to Pu isotopes and Am after explosion of glove box (Swiss case). Measurements of urine, feces, lungs, bone, liver, and lymph nodes available. Ingrowth of $^{241}$Am from $^{241}$Pu.</td>
</tr>
<tr>
<td>31</td>
<td>2</td>
<td>Acute Pu inhalation data for 12 years monitoring. Urine data available. One &lt;LOD data.</td>
</tr>
<tr>
<td>32</td>
<td>2</td>
<td>Several acute inhalations of Pu during 17 years. 10 potential dates of incidents provided. Urine data available. No use of DTPA.</td>
</tr>
<tr>
<td>33</td>
<td>2</td>
<td>Several acute inhalations of Pu during 17 years. 13 potential dates of incidents provided. Use of DTPA after 2 potential intakes. Urine data available. 12 &lt;LOD data present.</td>
</tr>
<tr>
<td>34</td>
<td>2</td>
<td>Several acute inhalations of Pu during 16 years. 7 potential dates of incidents provided. Use of DTPA after last potential intake. Urine data available. 12 &lt;LOD data present.</td>
</tr>
<tr>
<td>35</td>
<td>1</td>
<td>Wound uptake of $^{239/240}$Pu due to breakage of a flask containing Pu solution. Use of DTPA. Several &lt;LOD data. Urine and feces data available.</td>
</tr>
<tr>
<td>36</td>
<td>2</td>
<td>Accidental ingestion of $^{210}$Po after cleaning a research laboratory. Urine data available.</td>
</tr>
<tr>
<td>37</td>
<td>3</td>
<td>Accidental inhalation and wound of mixed Pu isotopes + $^{241}$Am after explosion of glove box. Use of DTPA. Lung, urine and feces data available.</td>
</tr>
<tr>
<td>38</td>
<td>2</td>
<td>Acute inhalation of Sr titanate during handling of a defective waste container with an old source of $^{90}$Sr. Urine measurements available.</td>
</tr>
<tr>
<td>39</td>
<td>2</td>
<td>Acute inhalation of Sr titanate in the same case scenario of case 48. Urine measurements available. 2 data &lt;LOD.</td>
</tr>
<tr>
<td>40</td>
<td>2</td>
<td>Chronic intake of U with unknown date of beginning of exposure. Known end of exposure. Urine, feces and lungs measurements available.</td>
</tr>
<tr>
<td>41</td>
<td>2</td>
<td>Chronic intake of U with unknown date of beginning of exposure. Known end of exposure. Urine, feces and lungs measurements available.</td>
</tr>
<tr>
<td>42</td>
<td>2</td>
<td>Chronic intake of U with unknown date of beginning of exposure. Known end of exposure. Urine, feces and lungs measurements available.</td>
</tr>
<tr>
<td>Case</td>
<td>Assessment</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>Accidental large intake of pure UF\textsubscript{4} powder in a furnace room with increase of the excretion after inhalation. Urine measurements available.</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>Accidental inhalation of \textsuperscript{125}I. Urine and thyroid data available.</td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>Acute exposure to \textsuperscript{3}H after performing tritium labeling with 4 GBq sodium borotritide. Urine data available.</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td>Contemporary injection of \textsuperscript{205}Tl as impurity of cyclotron produced \textsuperscript{201}Tl. WBC data available. 2 data &lt; LOD.</td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>Acute inhalation of \textsuperscript{90}Sr chloride. Urine and feces data available.</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>Acute inhalation of \textsuperscript{95}Zr. Lungs measurements available.</td>
<td></td>
</tr>
<tr>
<td>77</td>
<td>Acute intake of \textsuperscript{241}Am oxide. 1 measurement for lungs and nose blow. 8 data for feces, 5 data for urine &lt; LOD available. No DTPA used.</td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>Acute inhalation of UF\textsubscript{6} due to an accidental release of gas from storage cylinder. Urine partial excretion data available during the 3 first days.</td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>Accidental inhalation of enriched U after filter reloading. Lungs data for \textsuperscript{235}U available.</td>
<td></td>
</tr>
<tr>
<td>92</td>
<td>Acute inhalation of \textsuperscript{60}Co dust while unpacking a vessel which had become contaminated with dust during a grinding and polishing operation. WBC and organ (thorax and LLI) measurements available.</td>
<td></td>
</tr>
<tr>
<td>94</td>
<td>Protracted exposure to U (routine monitoring). Estimated annual excretion based on annual measurements. Urine and lung data available.</td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>Acute inhalation of enriched U oxide fumes during deburring enriched uranium metal. Urine and lung data available.</td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>Acute inhalation of enriched U in uranium casting area cleaning crucibles. Urine and lung data available.</td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>Routine monitoring for inhalation of \textsuperscript{125}I after labeling radiopharmaceuticals. Thyroid measurements available.</td>
<td></td>
</tr>
<tr>
<td>206</td>
<td>Accidental inhalation of \textsuperscript{241}Am oxide while examining old sealed source. Lungs, urine data available.</td>
<td></td>
</tr>
</tbody>
</table>

Two-thirds of the cases have been evaluated by two assessors, so from these evaluations the general methodology followed by assessors can also be extracted. For instance evaluator E4 allowed the software to be free to indicate something about the choice of parameters by considering a metric of goodness of fit, then make the choice for the best assessment. On the other hand the evaluator E2 used the default parameter values first then refined the evaluation working on parameters trying to reproduce, with adopted assumptions, the experimental values.

### 2.3 The Evaluation of Cases Database

The evaluations were presented by means of a Microsoft® Word file with descriptions of all the steps that led to the best estimate. Graphs of the output of the software used are also presented in it. Remarks related to issues that must be considered during the development of guidelines were also introduced in the majority of evaluations.

Generally the structure of the evaluation has the form:
- Brief description of case
- Issues important for the development of guidelines
- Hand or simple calculation of intake and committed effective dose (CED)
- Reference software evaluation (upgraded version of IMIE)
- Evaluation with other available software (IMBA Expert™)
- Indication of best estimated value
- List of data used in the assessment.
An evaluation database was set up to collect the evaluations and compare them, also considering assumptions and parameters involved.

To introduce a summary of the data in the Evaluation of Cases Database a record format (as an input Microsoft® Excel file) has been developed.

The record format used is presented in Table 2.3

**Table 2.3:** Characteristics of the record in the Evaluation of Cases Database.

<table>
<thead>
<tr>
<th>Case number</th>
<th>Radioisotope</th>
<th>Evaluator initials</th>
<th>Document file name</th>
<th>Comment on case</th>
<th>Type of monitoring used for the evaluation</th>
<th>Pathway of intake indicated in the case description</th>
<th>Characteristics of monitoring (special, routine etc)</th>
<th>Total number of data used in the evaluation</th>
<th>All data are selected? (Yes / No)</th>
<th>Mode of assumed intake</th>
<th>Assumed date of intake or beginning of the chronic intake period</th>
<th>Assumed pathway (may differ from the case description)</th>
<th>Assumed AMAD (µm)</th>
<th>Assumed Absorption type</th>
<th>Assumed f1</th>
<th>Used IMIE evaluation criteria</th>
<th>The evaluation is the result of the analysis of two or more datasets?</th>
<th>Evaluated intake (Bq)</th>
<th>Evaluated Committed Effective Dose (CED) (mSv).</th>
<th>Items of the case that are interesting for the guidelines.</th>
<th>Error assumption used (percentage, absolute, indicated in the case description)</th>
<th>Handling of data below limit of detection</th>
<th>Handling of data during or after chelation therapy</th>
<th>Performed conversion of units of data from those appearing in the DB</th>
<th>Criteria for the evaluation of the isotopic ratio when more radioisotopes present</th>
<th>Handling of outlying data</th>
</tr>
</thead>
</table>

These records are input in the Evaluation of Cases Database together with the link to the Microsoft® Word file that contains all the details regarding the evaluation.

The Microsoft® Excel file has also been prepared by the evaluators. Both files have the same heading: first the number of the case, then the evaluator and at the end the radionuclide. For instance, from the evaluation of case 27 by evaluator E6 and radionuclide $^{125}$I two files were produced: 27_E6_I125.xls as the record file and 27_E6_I125.doc as the document file with the complete details of the evaluation.
In the Evaluation of Cases Database it is possible to open the document file related to the evaluation being considered and also open the IDEAS Internal Contamination Database to review the original data and case scenario description if needed during the comparison of evaluations.
Chapter 3

Codes used for the evaluations

3.1 Introduction

The codes used for the evaluations have different characteristics. One is mainly a solver or evaluator of intake (IMIE), the other, IMBA Expert™, each time performs calculations solving a compartmental model that represents the given internal contamination, calculating both the intake value and the committed effective dose on the basis of experimental excretion/retention measured values.

It is beyond the scope of this report to describe in great detail all the characteristics of the software used. A recent comparison of software products has been performed by Ansoborlo and co-workers, considering amongst others the two codes used in the IDEAS project. [3]

3.2 IMIE

A complete description of the code is beyond the scope of this chapter and can be found in reference [4].

The code has been developed by the Radiation Protection Institute of Ukraine during the last 10 years. Originally it was developed as a supplement to the IDSS code that had been developed for the calculation of dose coefficients in the ICRP Committee 2 Task Group on Dose Calculations (DOCAL).

IMIE, used in IDEAS as the reference code, has been developed for the evaluation of committed effective doses to individuals on the basis of multiple measurements on the same subject. It contains an internal database in which the personal data (name, surname and date of birth etc.) of the subject are recorded together with the bioassay data related to the different monitoring types of measurements.

Models were not embedded in the code; instead the code uses tabulated bioassay functions. In particular for inhalation the retention/excretion functions are referred to unit activity deposited in the various sub-regions present in the human respiratory tract model. Making the convolution with the deposition pattern it is possible to reproduce the deposition of any particle size distribution of inhaled aerosol. The use of tabulated values for excretion/retention functions was considered to be an important feature for quality assurance of the code. The characteristics of IMIE are reported here.

- Route of intake could be inhalation, ingestion, or injection
- Pattern of intake could be acute(s) and chronic
- Simultaneous analysis of several data sets (e.g. urine and lung) can be performed obtaining a unique value of intake using all data simultaneously.
- Primary data (whole body count, thyroid, lung, urine, faeces, were entered in the form date; activity; error; comment)
- Personal data (“passport data” included name, ID code, main date of first possible intake, and text comments: this was linked to a worker database)
- Exposure conditions (possible times of intakes, route of intake, type of intake (acute/chronic) assumed by assessor, range of AMAD/AMTD, lung absorption type)

Classical interpretation schemes for routine, special and task-related individual monitoring have been recommended in ICRP Publication 54 [5] and ICRP Publication 78 [6], which replaced Publication 54 in 1997. Classical approaches have the following distinguishing features:

(a) Routine monitoring is carried out at regular intervals during normal operation. In data interpretation it is assumed that an acute intake occurs at the mid-point of the monitoring interval.

(b) 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 may be attributed to intake in previous monitoring intervals, for which intake have already been assessed, a relevant correction is recommended.
In special and task-related monitoring it is assumed that an acute intake has occurred and the time of intake is known.

In a case of inhalation all types of interpretation schemes demand \textit{a priori} information about the absorption Type of the materials and the aerosol particle size (in Publication 78 an AMAD of 5 µm is assumed).

This scheme could be used for the analysis of all cases of intakes of radionuclides. In many cases it gives acceptable estimation of the total intake, as far as it could be done at all. But this classical scheme has some substantial limitations, connected with approaches used.

The new method, introduced with IMIE, extends the possibilities of the classical ICRP scheme. The features of this data interpretation method are:

(a) Reconstruction of the intake on a basis of a multi-point approximation of observed trends of measurements.
(b) Possibility to use several data sets simultaneously (e.g. WBC and bioassay data).
(c) Approximation of observed data with the use of a set of tabulated retention and excretion functions, calculated in advance for an assumed range of exposure conditions. Arbitrary intake patterns can be used in such calculations. The matching and scaling of theoretical curves is performed in the interactive mode.
(d) Approximation, which involves an interactive numerical deconvolution and a recurrent optimisation of the data fitting during the deconvolution. The linear combination of time-shifted biokinetic model response (retention or excretion functions following an acute intake of unit amount) is used in this method.
(e) Possibility to assess the date and pattern of intake, the solubility of the aerosol (absorption type of materials) and its particle size.
(f) Interactive and automatic modes of data interpretation.

In the approximation a linear combination of biokinetic responses is built in the course of a multi-step optimisation process. The Manual or Semi-automated mode of data fitting helps the assessor to achieve the most reliable results.

IMIE enables the input of a flat text file to introduce values from an existing database and permits to saving the results and the graphs in files.

The general display of the code (Figure 3.1) is composed of the bar menu, the tabbed notebook with the possibility to display the original measurements (as displayed in the data manager section present in the centre of Figure 3.1) or the analysis performed on the data. In that case Intake, Distance, Relative Distance (see later in this paragraph) and committed effective dose (CED) are reported in relation to the date of acute intake, the days from a reference date, the inhaled material and the AMAD if considered. (In the case displayed there is elemental iodine $^{125}$I inhalation, and so no AMAD is displayed).

In the right side the displays of the original data (Urine, Thyroid and Relative Distance vs Date) with the fitted curves are reported.

Four modes of interpretation are available in IMIE:

- **ICRP78**: each time of intake is set at the mid point between two measurements, as indicated in ICRP Publication 78.
- **Smart mode**: the code evaluates with certain criteria (chosen by the evaluator and reported in Figure 3.2) how to join the next point and evaluate the presence of a further intake.
- **Manual mode**: the evaluator selects the number of data to be evaluated for an intake interval. The choice of a particular fitting is submitted to the evaluator’s judgement.
- **Semi-Automated mode**: the selection of data is identical to that performed for the manual mode but the choice of the fitted parameters is performed automatically on the basis of the goodness of fit “distance” value.
The different fitting modes permit performing of different degrees of evaluations. In IMIE it is possible to use different sets of bioassay measurements (e.g. urine + faeces + lung) simultaneously to evaluate the best fit. In the bottom left of Figure 3.1 the set of evaluated times and amounts of intake (with corresponding CED) are reported.

Figure 3.1: Display of a case of inhalation of elemental iodine $^{125}$I with urine and thyroid measurements available.

Figure 3.2: Criteria to join the next point to intake in Smart Mode

The goodness of fit parameter is the “Distance” $D$ between experimental and model value if the uncertainty connected with the measured values is not available, and the “Relative distance” $D_r$ if the uncertainty is known.
The two equations used for the calculation of these parameters are as follows.

\[
D = \frac{1}{j_2 - j_1} \sqrt{\sum_{k=j_1}^{j_2} \left( \sum_{i=1}^{n} I_i R_i(t_k - \tau_i) - M(t_k) \right)^2}
\]

and

\[
D_r = \frac{1}{j_2 - j_1} \sqrt{\sum_{k=j_1}^{j_2} \left( \sum_{i=1}^{n} I_i R_i(t_k - \tau_i) - M(t_k) \right)^2 \sigma_k}
\]

where

- \(k\) = index of the measurement of the radionuclide \(M(t_k)\) at time \(t_k\);
- \(i\) = index of the time interval, on which a single response can fit the selected subset of measurement series;
- \(n\) = current step number in the iterative analysis process;
- \(\tau_i\) = shift in the time of the \(i\)th acute intake; the shift \(\tau_i\) for the last term of the sum is a required time, when the currently reconstructed intake occurs;
- \(R_i(t)\) = response of the biokinetic model (response function) on a unit delta impulse (radionuclide content in the body, organs or in bioassay probes after a unit acute intake at \(t=0\) predicted by the model at time \(t\)), which was used during step \(i\) of the analysis; note that \(R_i(t)\) can change step by step in the evaluation so different absorption types or AMAD values can be used.
- \(\sigma_k\) = absolute uncertainty of the measurement \(k\);
- \(I_i\) = reconstructed intake on the step \(i\);
- \(j_1, j_2\) = index of the extreme left and right points of data series \(M(t_i)\) included into the current interval of approximation \(n\);

**3.3 IMBA Expert™**

The software IMBA Expert™ (Integrated Modules for Bioassay Analysis) has been developed since 1997 by NRPB to implement the new biokinetic models that the ICRP introduced during 1993-1995 to describe in a more realistic and scientifically justifiable way the internal behavior of radionuclides. As the nature of the models introduce a great complexity in compartmental modeling, NRPB decided to implement software that can deal with such complexity and to make assessment of intake and committed doses.

A special version (Version 3.0) of IMBA Expert™ was made available by NRPB for the evaluations to be performed by participants of the IDEAS project in the period up to end of September 2003.

The general description of the software can be found in a recent publication [7]. In it the status of the IMBA development has been also presented. IMBA Expert™ (Version 3.0) includes the capability to analyze multiple types of bioassay data simultaneously, for all radionuclides included in the Phase II developments of the IMBA Expert™ USDOE- and CANDU-Editions, and for some additional radionuclides. Future versions of IMBA Professional will be developed (by NRPB) to add new features and capabilities.
All versions of the IMBA Expert™ Professional Series software include the following basic features:

- Calculate the best estimate of the amount of intake - from a single exposure event (intake regime), based on the user-specified intake scenario.
- Analyse different types of bioassay measurement - for a given indicator radionuclide.
- Save all assumptions, parameter values and results to a single, nameable data file - which can be read in to any version of IMBA Expert™, running on any compatible PC computer system.
- Specify the date and time-of-day of each bioassay measurement.
- Track time as either date + hh:mm or fractional d.
- Specify the collection period for each urine and faecal sample (in fraction of a day).
- Import/export bioassay data between IMBA Expert™/Professional Series and a Windows® spreadsheet.
- Exclude unreliable data points from the fitting process - but not from the data record - and mark these as such in the associated graph of the data.
- Apply the maximum likelihood fitting method to deal with:
  1. data recorded as "less than the limit of detection" (< LOD);
  2. explicit error on each data point;
  3. normal or lognormal error distributions;
  4. up to 200 data points.

All software versions enable the user to:

- Obtain the best estimate of the amount of intake - repeating the calculation with the same assumptions and data yields an identical result.
- Calculate the committed equivalent dose to each organ or tissue - and the effective dose - from an indicator radionuclide.
- Toggle between ICRP60/68, ICRP26, or 10 CFR 835 tissue weighting factors and remainder tissue rules.
- Create a comprehensive report file containing administrative details, all case parameter assumptions, and the calculated results.
- Define all absorption parameter values and aerosol characteristics - or select the absorption parameter values from a built-in database of ICRP-recommended values.
- Define bioassay retention functions - or select these from a database of ICRP-recommended values.
- Enter user specified particle transport rates (in the respiratory tract) - or use ICRP defaults - and perform calculations for both Reference Worker (light activity) and heavy activity.
- Apply built-in ICRP biokinetic models for each radioelement - or specify user-defined models.
- Display bioassay data (with error bars and the fitted bioassay function) graphically on-screen - in multiple windows.
- Interchangeably display tables of bioassay data and predicted bioassay quantities with graphs of the same quantities.
- Use built-in, highly flexible, graphical and spreadsheet tools to facilitate setting up your graphs and data entry.
- Copy data to-and-from spreadsheets and other Windows® applications or an ASCII file.
- The ability to deal with chelated intakes - by marking and excluding "treatment enhanced" excretion data from the intake assessment.
• Apply the built-in ICRP Publication 38 radiation database - and view complete decay chains and nuclear data on-screen.
• Toggle between activity and committed effective dose units (pCi and Bq, rem and Sv).
• Calculate bioassay quantities over specified time intervals - for design of future monitoring programs.
• Save and reload all assumed parameter values and calculated results for a particular case study in a comprehensive parameter file.

IMBA Professional applies the maximum likelihood method to find the "best estimate" of Intake from a given set of bioassay measurement data. The IMBA module BNFL_FIT implements a published algorithm [8]. The validation of IMBA and IMBA Expert™ has been presented in a recent paper [9]. In particular the treatment of maximum likelihood method for data below the limit of detection has been evaluated.

The key components of the maximum likelihood methodology for evaluating the "most likely" estimate of intake in the case of single intake are reported here. To determine the "best estimate" of a single intake, IMBA Professional first derives a function \( f(t) \) which corresponds to a bioassay quantity following unit intake. It is required to determine the "best estimate" of the intake \( I \) such that the product \( I f(t) \) "best fits" the data \((m_i, t_i)\), as illustrated in Figure 3.3.

\[ \text{Figure 3.3. Set of measurements (*) shown with the product (line) of a fitted intake amount (I) and time-dependent function } [f(t)]. \]

Clearly, if \( I \) is made larger, then the curve (Figure 3.3) will move upward, and away from most (or all) of the data points. Similarly, if \( I \) is made smaller, then the curve will move downward, and eventually below all of the data. The objective of the maximum likelihood method is to select the value of \( I \) which is most likely to be correct.

Statistically, one cannot ask the question "What is the probability that \( I \) is correct?" This is because there is no statistical "universe" of intakes. There is just one intake, of the correct value, and a statistical universe of measurement data drawn from it. What can be done, however, is to turn the question around; and instead ask "For a given intake \( I \), what is the probability that this data set could have occurred?" Strictly, if the measurements, \( m_i \), take on continuous values, then the probability is always zero, unless the qualifier "plus or minus some fixed \( \Delta m \)" is added. If the probability of obtaining the data set is infinitesimally small, then it can be concluded that the value of intake \( I \) is "unlikely" to be correct. Conversely, and intuitively, the probability of the data set should not be too low for the correct value of intake. The probability of the data, given the intake, is thus identified with the likelihood of the intake, given the data. The probability of the data given the intake can be expressed mathematically, and thus calculated.

It should be noted that this direct identification of the likelihood of intake with the probability of the data is purely intuitive, and has no formal mathematical basis. However, once this identity is accepted, it is possible to define the "best estimate" as the one that maximizes the likelihood. This widely used form of parameter
estimation is known as the maximum likelihood method.

Probability of observing a value between $x$ and $x + dx$

In this section, it is understood that where the probability $P_i$ of a measured value $m_i$ is referred to, this is taken to be the probability that the measured value lies between $m_i$ and $m_i + \Delta m$, where $\Delta m$ is an arbitrarily small value.

If it is assumed that a variable $x$ is normally distributed around a mean value $\mu$, with a standard deviation $\sigma$, then the probability of observing a value between $x$ and $x + dx$ is given by $g(x) \, dx$, where:

$$g(x) \, dx = \frac{1}{\sigma \sqrt{2\pi}} \exp \left[-\frac{1}{2} \left(\frac{x - \mu}{\sigma}\right)^2\right] \, dx$$

Thus, the probability $P_i$ of observing a measurement $m_i$ is:

$$P_i \propto \exp \left[-\frac{1}{2} \left(\frac{m_i - I \cdot f(t_i)}{\sigma_i}\right)^2\right] \Delta m$$

and the probability of observing all of the data set is:

$$P \propto \prod_{i=1}^{i=n} \left( \exp \left[-\frac{1}{2} \left(\frac{m_i - I \cdot f(t_i)}{\sigma_i}\right)^2\right] \Delta m \right)$$

Maximizing $P$ is equivalent to maximizing its logarithm, or minimizing the negative of its logarithm, i.e.:

$$\left( \sum_{i=1}^{i=n} \left[\frac{m_i - I \cdot f(t_i)}{2\sigma_i^2}\right]^2 \right) - n \log \Delta m$$

Since $n$ and $\Delta m$ are constants, this is equivalent to minimizing the quantity $S$ where:

$$S = \sum_{i=1}^{i=n} \left(\frac{m_i - I \cdot f(t_i)}{\sigma_i}\right)^2$$

Note that, if a residual is defined as the number of standard deviations that a measurement value $m_i$ is away from the fitted function $I \cdot f(t_i)$, then application of the maximum likelihood method is equivalent to minimizing the sum of the squares of the residuals.

The main screen of the software IMBA Expert™ is given in Figure 3.4.

It shows the different boxes below the tool bar (from top left to bottom right): intake scenario, in which the intake regimes must be specified with the pathway of supposed intake; the units section to select units for time, intake and dose; the evaluated intake from the bioassay calculation (for intake regime 1) the indicator nuclide and the associated radionuclides. “Model parameters” is the box where the user can introduce default or subject specific parameters for the different models (e.g. deposition, particle transport, absorption, GI-tract, bioassay, biokinetics etc.). The 2 main buttons in the box “Calculations” are for bioassay and for dose calculations.
Clicking on the relevant button it is possible to open the tool “Bioassay calculation”. It is possible to perform 2 main evaluations: from “bioassay to intake” as depicted in Figure 3.5 (fitting procedure) or from “intake to bioassay” as shown in Figure 3.6.

In the input several data types must be introduced: the measurement time, the collection period of the measurement (for bioassay values), the measured value, the data type. This last parameter can be of three types: “Real”, “Imaginary” or “<LOD”. The last values to introduce are measurement error, and error distribution which can be normal or lognormal.

![Figure 3.4](image)

**Figure 3.4:** Main screen of IMBA Expert™

The selection between the data type is based on the use of them during fitting. “Real” data are used during fitting. “Imaginary” (excluded) data are not used but are present in the database and “<LOD” flagged data are considered during maximum likelihood estimation.

An advanced tool permits calculation of the value of chi-squared for the data above the detection limit (those flagged “Real”). In some evaluations this advanced option (available only at few evaluators, E9, E2, (see Chapter 6), permits comparison of best fits to data. In the software there is the possibility to use site specific parameters (e.g. AMAD values) and different compound specific absorption parameters. This possibility has been widely used by some evaluators to improve the fit of the experimental data. It is also possible to use different bioassay data sets simultaneously (e.g. use of urine and lung measurement data). This can be performed by selecting the available data sets in the “bioassay to intake” option as depicted for “Whole Body” and “Urine” in Figure 3.5.

After having evaluated the amount of intake for the specific intake regime (single or continuous intake from a given start and end) IMBA Expert™ allows the calculation of the committed equivalent doses to all the organs, the weighted equivalent doses and the committed effective dose. For this calculation it uses the Specific Effective Energy (SEE) library used for the calculation of the ICRP Publication 68 [10] dose coefficients.
In complex dose evaluation when multiple intakes can occur, it is possible to combine acute and chronic intakes but the time of intake of the single intake regime must be provided to the code. This is an important difference between IMBA Expert™ and IMIE. In IMIE it is possible to evaluate the best time of intake by means of the goodness of fit parameter, and via Semi-Automatic mode consider, step by step, both single and chronic intakes. It is not possible in IMIE (in contrast to IMBA Expert™) to superimpose some acute intakes over a prolonged continuous intake. For each time period a unique mode of intake must be introduced.

Figure 3.5: Bioassay calculation: from Bioassay to intake
Figure 3.6: Bioassay calculation: from intake to bioassay.

After making the dose calculation IMBA Expert™ presents the value of committed effective dose connected with the evaluated intake and the committed equivalent organ doses. This tabulation is presented in Figure 3.7.

Figure 3.7: Result of dose calculation

3.4 Comparison of the two codes

From the point of view of the user the two codes are considered to be complementary as different options are available for each one of them. IMIE uses the excretion and retention curves embedded inside the code in tabular form and these are related to the ICRP categorization of compounds. It is not possible to change the absorption parameter values related to the type of compound. It is only possible to evaluate a mix of different compounds (e.g. 50% type M + 50% type S). Although it is possible for the user to introduce in IMIE retention/excretion functions calculated independently on the basis of parameters different from that used by ICRP, usually the supporting code IDSS [11] to perform the calculation and produce the tables (and in particular, the corresponding doses per unit intake). As far as deposition is concerned, if the percentages of deposition of the aerosol, different from the introduced values present inside the code, are known, it is possible to input the deposition percentages values easily and to evaluate doses due to inhalation of aerosols with AMAD values different from those already present in IMIE. IMIE is able to display the experimental values and several fitted curves at the same time. This is helpful to compare different times of intake, different pathways (inhalation versus ingestion) or different AMAD values or absorption Types.

In IMBA Expert™, for each run the code performs the calculations related to retention/excretion functions, on the basis of a non recycling compartmental model equivalent to the recycling one, for the given radionuclide. In IMBA Expert™ it is possible to change each parameter and introduce compound specific absorption parameter values. Also, the deposition pattern can be modified simply by changing the values of AMAD and geometric standard deviation without introducing the deposited percentages in each region. IMBA Expert™ performs the calculation. The number and the type of intake regimes (either single or continuous and for which period) must be introduced in advance. So in this case there must be at least some previous indication of the number and the
times of the suspected incidents or continuous exposures. A comparison between different times of intake can only be made by performing several runs.
In IMBA Expert™ it is possible to visualize in the same graph the experimental values and the fitted curve. A difference from IMIE is that only one curve at a time can be displayed.
Under the same conditions of evaluation (same data, same parameters of models) the same fitted parameters (intakes, times) were obtained with both codes. Thus some validation of the codes has been performed in several cases evaluated during the period of use of both codes.
Chapter 4

Data

4.1 Introduction
The very first approach to dose assessment is related to the evaluation of the available data sets and inside each
data set the evaluation of the specific data. This is mainly needed:
- to make the measured quantities coherent to the model related values,
- to estimate realistic uncertainties on the measured data taking account of different components of
  uncertainty and to estimate uncertainties for any < LOD data
- not to give undue weight to some part of the monitoring period due to the number of measurements
- to consider outlying data
- to use the early data in the evaluation
- to make the proper choice of the monitored quantity in relation to model parameters.(e.g. Whole body vs
  Lung measurements)

In this phase one must take into account several aspects that at the beginning of the evaluation can affect the
assessment.
In this chapter the information from the performed evaluations (as they are reported in the record files connected
to the database), the choices made by the evaluators in the absence of specific information, and the effect of the
different assumptions on intake and dose assessment will be summarized. The cases for which two evaluations
are present will be considered first.

The aspects taken into account are the following:
- Conversion of data
- Uncertainties of data. Uncertainty connected to <LOD data points.
- Grouping of data
- Outlying data (rogue data): definition, exclusion (only below the expected value as measurements above
  the expected value can always be due to a further intake).
- Early data (single void for urine or feces)
- Interpretation of data : Data for whole body considered to be related only to lung
- Best monitoring type to evaluate intake or CED

4.2 Conversion of data
The item is particularly important when the measurements provide general information such as “total amount of
U”, or “Pu alpha”. In these cases some assumptions must be made for the isotopic composition or the mix of
radioisotopes.

_Uranium_
In several cases the conversion from e.g. total Bq of U to Bq of the different radionuclides had been already
performed by the person who submitted the case in order to the data into the IDEAS Internal Contamination
Database. For the correct dose assessment it was important to take note of this.

In case 13 the urine excretion data are presented in µg/d, total U activity Bq/d and Bq/d for each radioisotope. The
isotopic composition of the 3 radioisotopes of U is thus available for the later measurements; the isotopic
composition of the early data was evaluated by both evaluators E4 and E7 on the basis of the mean values of the
later data. The activity percentages are similar for the two evaluators and are different from default low
enrichment ratios. The experimental activity percentages are $^{234}U = 78.1 \%$, $^{235}U = 4.8 \%$, $^{238}U = 17.1 \%$. The
reference percentages in activity, for an enrichment of 3.5% $^{235}U$ by mass, are $^{234}U =81.84\%$; $^{235}U = 3.44 \%$, $^{238}U$
= 14.73 \%. So in this case site-specific information on isotopic composition has been used.
In case 51 (Urine, feces and lung data always indicated as Bq U or Bq U /d after chronic exposure) the evaluator E7, in absence of indication, has used an isotopic composition of HEU as follows: by mass $^{234}\text{U} = 0.00205 \%$, $^{235}\text{U} = 93 \%$, $^{238}\text{U} = 6.99795 \%$ and by activity $^{234}\text{U} = 5.90 \%$, $^{235}\text{U} = 93.01 \%$, $^{238}\text{U} = 1.03 \%$.

In case 84 (single urine voids after inhalation of UF$_6$) the original data in mg/L have been converted into Bq($^{238}\text{U}$)/L using the conversion factor 12.4 Bq($^{238}\text{U}$)/mg(U). Both evaluators (E2 and E3) make the dose assessment only for $^{238}\text{U}$ but indicate to add as much dose as evaluated to take into account doses from $^{234}\text{U}$.

In case 91 (lung data for $^{235}\text{U}$ after changing of filters loaded with Highly Enriched Uranium, HEU) the lung monitoring is performed on $^{235}\text{U}$ which is the isotope that does not give the highest dose. One of the evaluators (E2) gives this isotopic composition by mass for High Enriched Uranium (HEU): $^{234}\text{U} = 0.79 \%$, $^{235}\text{U} = 92.8 \%$, $^{236}\text{U} = 0.34 \%$, $^{238}\text{U} = 6.06 \%$. The percentages by activity are as follows $^{234}\text{U} = 95.642 \%$, $^{235}\text{U} = 3.891 \%$, $^{236}\text{U} = 0.428 \%$, $^{238}\text{U} = 0.039 \%$. So the activity ratio between $^{234}\text{U}$/$^{235}\text{U}$ = 24.6. The other evaluator E3 considers the activity of $^{234}\text{U}$ equal to that of $^{235}\text{U}$ and evaluated the dose according to the $^{234}\text{U}$ dose coefficient.

In case 94 of protracted exposure to uranium there is no indication of subject specific ratios between the radioisotopes of U. As in the working history the subject has been exposed from fully depleted (0.2 % $^{235}\text{U}$ by mass) to 4% $^{235}\text{U}$ enrichment, guidance must be provided for the activity conversion. For urine measurements the database provides $\mu$g/L of U. The Evaluator E2 has converted the values in Bq/L assuming 0.0124 Bq($^{238}\text{U}$)/$\mu$g.

In case 102 the two evaluators E1 and E7 have both selected the conversion indicated in the case description with an important percentage of activity connected with $^{234}\text{U}$. The percentages in activity are different: 78 % for E1 and 81.8 % for E7.

**Mix of Pu isotopes**

In case 14 (acute inhalation in reprocessing plant of Pu-IV, Pu nitrate with no $^{241}\text{Am}$) the initial percentages reported in the case description are: $^{238}\text{Pu}=0.30\%$, $^{239}\text{Pu}=78.65\%$, $^{240}\text{Pu}=14.64\%$, $^{241}\text{Pu}=5.55\%$, $^{242}\text{Pu}=0.001\%$ $^{241}\text{Am}=0\%$. The 7 urine measurements for $^{241}\text{Am}$ are available from 23 to 24.5 y after incident. Other measurements spanning between the first days after the accident up to more than 22 y are related to “Pu”. From 22.5 y and 24.6 y after accident are available measurements related to “$^{238}\text{Pu}$” and “$^{239}\text{Pu}$”. Other available measurements relates to 3 teeth (23 y after the accident) are related to $^{238}\text{Pu}$, $^{239}\text{Pu}$, $^{241}\text{Pu}$ and $^{241}\text{Am}$.

In this case (and in the following cases 15 and 16, related to other subjects involved in the same incident) the choice of the evaluator E2 has been that to consider “Pu” (if not qualified) as ($^{238}\text{Pu}+^{239}\text{Pu}+^{240}\text{Pu}$). When indicated “$^{239}\text{Pu}$” it has been assumed that the measurements refers to $^{239}\text{Pu}+^{240}\text{Pu}$ because in alpha spectrometry it is not possible to distinguish between the 2 radioisotopes.

The other evaluator E4 indicates that considering the 10 urine data from 8200 to 9000 days post-incident the alpha activity ratios between $^{238}\text{Pu}+^{240}\text{Pu}/^{239}\text{Pu}$ results in 61.6%/38.4%. This corresponds to the alpha activity ratios indicated in the case description. So in this case there is a verification of ratios of activities during the accident in the Pu mix using the values internal to the dataset (late data) in the subject.

As far as the $^{241}\text{Am}$ is concerned there is no presence during the incident. The late teeth measurements can be used to evaluate the ingrowth from $^{241}\text{Pu}$ as performed by E2.

In case 39 (a selected Hanford case of a single inhalation with no use of DTPA) as the isotopic ratio is not given the evaluator E2 assumes for the urine measurements “Pu” as $^{239}\text{Pu}$ as substitute of Pu-alpha neglecting $^{241}\text{Pu}$. Also the other evaluator E4 make the same assumption.

In case 40 (several acute Pu inhalation episodes over 17 years with 10 potential incidents, no chelation) in absence of information both the evaluators have assumed for “Pu” in urine the value of $^{239}\text{Pu}$.

In case 43 (several acute Pu inhalation episodes over 14 years with 13 potential incidents, after 2 of them the worker receives DTPA treatment) all “Pu” was considered to be $^{239}\text{Pu}$ as a surrogate of Pu-alpha. $^{241}\text{Pu}$ was neglected by both evaluators E2 and E4.

In case 44 (7 potential inhalation intake incidents over a period of 13 years with 7 DTPA treatments over a period of 21 days following the last incident date) the evaluators have made assumptions as in the previous cases.
The choices performed by the evaluators for cases 14-15-16 (with assumptions of the different radioisotopes) with verification internal to the dataset can be a basis for guidance. Also the indication of considering only $^{239}$Pu as surrogate of Pu-alpha can be used in guidance.

When there is the Pu composition in activity of Pu-beta ($^{241}$Pu) and total alpha ($^{238}$Pu, $^{239}$Pu, $^{240}$Pu and $^{241}$Am) as in case 47 (inhalation + wound due to explosion of glove box) reference should be made to the data. In that case the ratios by activity are: $^{239}$Pu/$^{241}$Am = 4.62; $^{239}$Pu/($^{238}$Pu+$^{239}$Pu+$^{240}$Pu) = 0.513. $^{241}$Pu/($^{238}$Pu+$^{239}$Pu+$^{240}$Pu+$^{241}$Am) = 95.9/4.1 = 23.4.

Tritium cases

Usually the $^3$H measurements are not based on daily excretion as is done practically for all other radioisotopes. This is due to the fact that the activity concentration in all body fluids is assumed to be the same as that measured in the urine. Conversion from Bq/L to Bq (whole body) or Bq/24h for the $^3$H is thus needed. In the $^3$H cases (6 and 23) the original urine data present in the case descriptions are reported as Bq/L. In case 6 (controlled test related to wearing a wristwatch which was leaking tritium), to use the daily excretion evaluator E2 used the conversion factor of daily excretion = 50% daily water loss and reference daily excretion rate of 1.4 L/d. This was considered on the basis of the previous ICRP 23 reference document. As an alternative it is possible to consider the concentration in urine = to the concentration in body water and 42 L of total body water to achieve the whole body activity.

In case 23 (acute inhalation in an incident during sealing an ampoule of $^3$H) the evaluator E2 indicates also the daily urinary excretion on the basis of the revised Reference Man in ICRP 89 equal to 1.6 L/d. The normalization factor to evaluate the daily total water loss is 2.9 L. For the normalization to the daily urine excretion 1.6 L/d multiplied by concentration can be used.

Correction of data for physical decay

As specifically indicated in the dataset of case 2 (accidental injection of $^{32}$P) the urine data have been corrected for radioactive decay. To perform the evaluation in this case the radioactive decay must be added. In performing the evaluations of case 29 related to $^{192}$Ir and selecting a surrogate nuclide to use in the IMIE software attention must be taken in performing decay correction of monitoring data as done by evaluators E2 and E6.

Indication for the guidelines:

Consider the criteria to verify the ratio of different radioisotopes in a mixture using data inside the same data set (e.g. later measurements) either on the same subject but in another type of monitoring (e.g. feces,) or externally from the monitoring data sets (case description).

Provide some reference percentages for the U composition at different enrichment ratios (depleted uranium, natural uranium, low enriched uranium, high enriched uranium).

Provide some reference ratios values for Pu-Am mixtures encountered in different types of facilities.

Make explicit indication to correct measured data for radioactive decay if not considered in monitoring values.

4.3 Uncertainty of data (uncertainty connected with < LOD data points)

During the phases of assessment of intake it is important to evaluate the uncertainty associated with the monitoring data. Also in some specific software information related to the uncertainty of the bioassay values must be given.

A general presentation of the variance models that can affect the intake evaluation and the way of fitting the data can be found in work by K W Skrable and co-workers in which they illustrate how a specific model parameter can affect the intake evaluation.

It has been supposed that the general uncertainty connected with bioassay measurements can be divided into 3 parts.

A Poisson behavior related to the measurement of the sample. This term of variance is proportional to the measured value (first order term) and it is inversely proportional to the net count per unit amount of the measurement device present in the bioassay sample.
A Poisson behavior related to the background counting. This term of variance is constant and not proportional to the measured value (zero order term). It depends on both variance propagated from the predicted background events on sample time and on the variance propagated from an independent background count observed on background time. These terms are usually unknown as they depend on the detection efficiency of the measurement device, the background count itself, the duration of measurements of the background and the sample+background count.

A biological variance that takes into account e.g. day by day excretion variability. This term of variance is proportional to the square of the measured value (second order term) via a constant relative term.

The authors of the paper indicate that if it is dominant the constant relative biological variance the best way to make the assessment of intake is related to the so-called “Slopes weighted least squares fit”. If the Poisson variance of analytical measurement is dominant it is better to use the so-called “ratio of the means weighted least square fit”.

In this section the examples of uncertainties reported in the cases are indicated. In the next section mention will be made of the different assumptions performed by the various evaluators. The evaluation is indicated by case number and identification of evaluator: e.g. 60_E1 = case No. 60, evaluator E1

Examples: uncertainties present in the case scenario’s description

$^3\text{H}$
1-19% as in Case 6

$^{60}\text{Co}$ in Whole Body
2% or less in case 18
10% in case 92

$^{125}\text{Iodine in Thyroid}$
5.3% to 15% as counting statistics in thyroid measurements in case 27.
9.3 % to 22% as counting statistics in thyroid measurements in case 28.

Gamma emitters in lung
10% to 90% for $^{95}\text{Zr}$ in lung measurements (case 75, 5 data)

$^{89}\text{Sr}$ in urine
12%-56 % in urine as in case 7

$^{235}\text{U}$ in lung
Constant experimental error at 95% confidence interval = 10 Bq. This represents 18%-48% for 55-21 Bq range in case 91.

Pu in urine
Experimental values 16% to 75% as in case 14
Experimental values 21% to 76% as in case 15
Experimental values 16% to 62% as in case 16

U in urine
Mean experimental values in the same dataset = 12% for $^{234}\text{U}$, 28% for $^{235}\text{U}$, 16% for $^{238}\text{U}$ in case 13.

Am in Lung
31% in case 77
Choices performed by evaluators

\(^3\text{H}\)
5% as in 22_E3 (measured on weekly basis; set 75 Bq/d ±100% if data is not available, 2 measurements)
2% for >1 MBq/d and 5% for < 1 MBq/d as in 23_E3
Several assumptions in case 63: Log-normal distribution with \(\sigma_g = 1.1\) in 23_E2 and 63_E2; constant error = 100 Bq/L which represent 21%-1000% of data range in 63_E2.

Fission products / activation products in Whole Body
10% in 1_E7 for \(^{137}\text{Cs}\) in WBC
5% in 9_E1 for \(^{137}\text{Cs}\) in WBC
No errors have been used in 9_E6 for \(^{137}\text{Cs}\) (repeated ingestion after Chernobyl)
20% in 18_E5 for \(^{60}\text{Co}\) in WBC
Additional 10% uncertainties in 18_E6 for \(^{60}\text{Co}\) in WBC
5% for \(^{192}\text{Ir}\) in 29_E2
Additional 10% uncertainties in 29_E6 for \(^{192}\text{Ir}\) in WBC

Iodine in Thyroid
10% in 60_E1 for \(^{125}\text{I}\)
10% in 106_E1 for \(^{125}\text{I}\)

\(^{90}\text{Sr}\) in urine
15% in urine as in 1_E7
15% in urine, 15% in feces, 10% in WB measurements in 26_E7
10% in urine in 48_E4 and in 49_E4
15% in urine in 48_E7 and in 49_E7
10% in urine and feces in 65_E4

\(^{32}\text{P}\) in urine
15% in urine as in 2_E7

Gamma in urine
10% for \(^{125}\text{I}\) in urine, evaluation 60_E1.

Pu in urine
\[
\begin{array}{cc}
10 \% & \geq 10 \text{ mBq} \\
15 \% & \geq 9 \text{ mBq} \text{ and } < 10 \text{ mBq} \\
25 \% & \geq 1 \text{ mBq} \text{ and } < 9 \text{ mBq} \\
30 \% & \geq 0.5 \text{ mBq} \text{ and } < 1 \text{ mBq} \\
40 \% & < 0.5 \text{ mBq}
\end{array}
\]
as in 40_E4, based on evaluation of uncertainty connected to the measuring procedure of urine as reported in 16.
Same pattern of variable percentage uncertainty introduced in 39_E4.
5%-20% based on indication of previous report in 11_E1.
10%-90% based on indication of previous report in 30_E1.
50% + lowest value in the dataset for the evaluation 31_E2.

Am in urine
Increased all data up to 80% in 14_E2
Lognormal distribution \(\sigma_g = 1.8\) as in 206_E9

Am in Lung
Set 30% to all lung data in 206_E9 + normal distribution
Am in Liver
Set 30% to all liver data in 206_E9+ normal distribution

Am in skeleton
Set 50% to all skeleton data in 206_E9 + normal distribution

Pu in feces
50% + lowest value in the dataset for the evaluation 31_E2

Am in feces
Increased all data up to 80% in 14_E2

\(^{210}\)Po in urine
15% in 46_E7
7% in 46_E4

U in urine
10% in 104_E1 for urine and lung measurements
10% in 58_E2, then set at 20%. For IMBA set lognormal distribution with \(\sigma_g=1.8\).
Set lognormal with \(\sigma_g=1.3\) in 84_E2 for single voids in IMBA. Set 10%-20% for the 3 grouped data in 84_E2
Set 30%-200% for the 3 grouped data in 84_E3.

Errors connected with < LOD data
100% for \(^{239}\)Pu urine data in 5_E1 (lot of data points)
100% and reconstruction of data point in evaluation 22_E3.
LOD replaced by LOD/2 + 100% uncertainty in 30_E1 for \(^{238}\)Pu and \(^{239}\)Pu.

Criteria of creation of uncertainty values
Some evaluators indicate the criteria that they have chosen to assume a certain uncertainty. Mainly 3 criteria have been reported:
- Evaluation based on adjacent points as in case 14 for both evaluators (E2, E4)
- Comparison with the variation between sequential measurements (as in evaluation 15_E2). Given measurement errors are much less than variation between sequential measurement.
- Assumption of the constancy of uncertainty in the same subject during the time and evaluation based on later data of the same subject (as in 13_E7)

Normal and Log-normal distribution of uncertainty
As in the IMBA software there is the need to specify the distribution of data points (including the parameter of dispersion) in many cases the evaluators have used lognormal distribution assuming as parameter of dispersion the geometric standard deviation \(\sigma_g\) that for the measurement of actinides in urine has been set equal to 1.8, based on the experience of reference 17 (as done in 58_E2, 15_E2, 16_E2, 39_E2)
Smaller values of the \(\sigma_g\) parameter are also reported (\(\sigma_g=1.1\) in 23_E2 and 63_E2 for \(^3\)H, \(\sigma_g=1.3\) in 84_E2 for U in urine related to single voids).

Indication for the guidelines:
Consider the experience gained on uncertainty in data for the different monitoring types and propose default values for uncertainties related to type of monitoring and amount of measured radioactivity, considering also the assumptions adopted by evaluators.

4.4 Grouping of data
Sometimes the available data set is populated differently in the different parts of the monitoring period. A reason to have the first part of data densely populated is e.g. the case of special monitoring after an accident. The very first measurements are much more frequent than those preformed some time after the accident.
On the other hand in routine monitoring during several years the suspicion of having an incident can increase the frequency of monitoring. The improvement in the number of detection devices in the monitoring laboratory over the years can also make it simpler to perform repeated measurements on the same subject. In that case the sparse early measurements give way to more frequent monitoring. This uneven distribution of data can cause, unintentionally, a weighting of the monitoring results giving more importance to the part of the monitoring interval that is most densely populated. To avoid this undue weighting of measurements grouping of data has been performed in some cases.

Examples of grouping of data
In case 14 (acute inhalation in reprocessing plant of Pu-IV, Pu nitrate with no \(^{241}\text{Am}\)) both evaluators E2 and E4 have grouped the late data considering instead of the actual data a unique value (the average of the values that lay in the period considered) set in the middle of the period over which the average of the data was made. The averaging period is 1 year for E4 and 1000 d for E2. The uncertainty connected with the value is set on the basis of the uncertainties of adjacent points. The evaluator E2 has used the same criteria of averaging also in similar cases 15 and 16. In these cases the uncertainty connected to the 1000 d period average is the sample standard deviation of the original data.

In case 31 the grouping of the values of the fecal excretion on days 1, 2 and 3, divided by the amount in lung at day 3 has been used to evaluate the AMAD of the aerosol. The curve indicated by E2 shows a monotonic increase in the ratio with increase of AMAD value, with no significant difference between Type M and Type S. The figure is that named E6.1 in Annex E: Illustrative examples of reference 18 reported also in the evaluation 31_E2. In this case the summing of the fecal activities excreted during the first 3 days is a basis for AMAD evaluation.

In case 84 the evaluators (E2 and E3) grouped the original 19 data points (single voids) during 3 days into only 3 average values taking the average of the results of each day. In this case the purpose is not to overcome the problem of weighting the data but to make them coherent with the daily urinary excretion considered in the model. The results in the original database are in Bq/l at fractional hours after the intake during the first three days. Evaluator E2, not knowing the volumes excreted each time, assumes the same volume and take the average of the concentration for each day. Then he converted the average concentration to the daily excretion rate multiplying by 1.4 L/d.

The evaluator E3 uses the concentration data at 2.5, 22.3 and 49.2 hours post intake to evaluate a daily excretion rate. In Table 4.1 the original data on which the assessment has been performed, are reported.

<table>
<thead>
<tr>
<th>Day</th>
<th>Result of summation (Bq/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Evaluator E2</td>
</tr>
<tr>
<td>1</td>
<td>14.8</td>
</tr>
<tr>
<td>2</td>
<td>0.70</td>
</tr>
<tr>
<td>3</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Evaluator E3 provides values for the 3 days that are more than a factor of 2 greater than that indicated by evaluator E2. This indicates the necessity to give advice for computing the daily excretion on the basis of urine concentration measurements in single voids.

Indication for the guidelines:
Consider the experience gained in grouping of data to provide criteria not to give undue weight to some part of the monitoring interval.
Indicate the proper way to calculate daily excretion rates on the basis of concentration measurements in single voids.
4.5 Outlying data
In some cases the presence of a data point greater or less than that expected by the behavior of precedent points lead the evaluator to consider it as an outlier, or a “rogue” result and to exclude the data point from the evaluation.

Examples of exclusion of data are here reported.

In case 13 (chronic intake of $^{238}$U) the evaluator E4 has discarded the first 6 data points taken at the end of a chronic intake. Data after the removal of the subject from the exposure clearance phase have been used for the dose assessment.

In case 16 (inhalation of Pu) the first 2 (18 and 29 d) points have a value smaller then the following point. The maximum is reached at day 71. Including these 2 data resulted in the evaluation of the intake being underestimated; so the evaluator E2 choose to discard them.

In case 29 (inhalation of $^{192}$Ir) the last data point does not fit the behavior of the others. Evaluator E2 discards the value from the fitting. (This is due to a transcription error in the data entered in the database. The data point should have a date 1 year later)

In case 48 (12 points are available) a data point at 46 d presents a value that is about 1 order of magnitude less than the value interpolated on the basis of the behavior of the other data points. Both the evaluators (E4 and E7) have discarded it from the dose assessment. If used in IMBA code the data point has a strong influence in the fitting pulling the fitted curve down.

In case 31 (acute exposure of Pu isotopes (Swiss case)) the nose swab value has not been used in the assessment from evaluator E2 as considered to be the activity in ET1 compartment which would have been removed by nose blowing. It would not affect measurements of lung, urine and feces.

In some cases the lung at day 0 have been eliminated; e.g. in evaluations 91_E2 or in 29_E6.

Evaluator E6 indicates in case 29 that the first early measurement is usually rather influenced by the error due to the differences of isotope distributions within the body closely after the incident and to that applied during calibration. That’s why if the early measurement is not fitting well to the further data then it is reasonable to disregard it in the fitting procedure.

Another difficulty is also related to the fact that the used IMIE code version does not accept day 0 values. IMBA Expert™ can manage also these data accepting also fraction of days for reference time.

In case 39 (80 data are available over 12 years for a Pu acute inhalation case) the evaluator E4 has excluded early and late data as “they pull down the fit” (i.e. result in the other data being underestimated). Also the other evaluator E2 has used the exclusion of the first few data points before 10 d.

In case 46 (polonium ingestion) it is not possible to fit the 1st point as it is a factor of 3 greater than the value interpolated on the basis of the following data. Both evaluators E4 and E7 have discarded it from the assessment.

Indication for the guidelines:
Consider the experience gained and give criteria to exclude data.

4.6 Early data
The use of early excretion data is sometimes considered not to be appropriate as the model values for the early days are considered to be not reliable. Thus the model values associated at times representing fraction of days are not usually available. This is more important in the case of excretion bioassay, especially with urine, in which the collection and measurements of single voids can be performed. In case 84 (related to accidental inhalation of UF$_6$) 19 uranium urine concentration values are available during the first 2.5 days. Concentration without indication of excreted volume is available. Evaluator E2 normalizes the values to daily excretion multiplying the values by the 1.4 L/d factor and then taking the average during each day (positioning it at the end of the day). The comparison with the model daily excretion permits to have the evaluation of intake. Not great difference has been pointed out by evaluator E2 if making dose evaluation using single data or mean daily excretion data. With similar error assumptions [(10-20%) grouped data and $\sigma_g=1.3$ for single data] the
committed effective dose evaluated via single data is only slightly overestimating (13%) the evaluation based on grouped data.

**Indication for the guidelines:**
*Consider if the models developed for prospective dosimetry can be used in interpretation of early measurements.*

### 4.7 Interpretation of data: data for whole body considered to be as only related to lung

The problem arises when a direct measurement such as a whole body measurement is performed after inhalation of a compound of a gamma emitter with slow lung absorption. Practically all the activity remains in the lung. The whole body activity in that case is mainly represented by the activity present in the lung. If a Whole Body (WB) Measurement has been performed, the information is related to the whole body but the lung retention function also, in principle, be used. The experience of the evaluators of cases 18 and following indicates that the evaluation based on WB expected values (considering the data related to WB measurements) is better than that based on lung expected values (evaluation 18_E5).

**Indication for the guidelines:**
*Use model data related to the part of the body that has effectively been measured.*

### 4.8 Best monitoring type to evaluate intake or CED

Several cases permit the evaluation of the choice of the best monitoring type of measurements for a certain output namely for the evaluation of intake or CED.

In case 1 for $^{90}$Sr intake evaluation Evaluator E7 adopted the intake value and absorption type indicated by fitting urine data (Type S) and considered this to be the best estimate. The CED estimated from feces measurements is lower by more than a factor of 3 compared to the best estimate value.

In case 12, considering freshly prepared Pu, where many urine data are $<$ LOD, Evaluator E9 indicates: “The estimated intake from the urine data alone is less than that from the faecal data by a factor of 2.4.” This can be justified by the presence of so many $<$ LOD data in urine measurements. Simultaneous use of urine, faeces and lung monitoring data in IMBA, after having tuned some absorption and particle transport parameters to obtain model behaviour simulating lung absorption slower than type S, permits to obtain a best fit for the case (see also paragraph 5.4).

In case 26 related to $^{90}$Sr, evaluator E7 indicates that faeces data were not considered to be reliable so the best evaluation is based on simultaneous use of whole body and urine data.

In case 31 ($^{241}$Am and $^{239}$Pu evaluations of Type S compound) where both lung and faecal data are available, evaluator E2 indicates that the assessment of intake and dose from the faecal data led to a large underestimate of the dose based on direct measurements of the lung. It appeared that the subject had much slower particle transport rates from the lung than taken in the model. His best evaluations for $^{239}$Pu and for $^{241}$Am are based on urine data in IMIE. Evaluator E9 performs the evaluations for $^{239}$Pu on the basis of urine and faeces; for $^{241}$Am on the basis of lung, urine, faeces, liver and bone data in IMBA Expert™.

In case 45, for wound incident with DTPA treatment, the decreased urine data (after elimination of DTPA effect) and faeces data were simultaneously used by Evaluator E9.

In case 47, for which there were multiple data, evaluator E2 indicates that the $^{241}$Am data probably provide the best estimate of the inhalation intake and dose, because there are more (and better) lung data for $^{241}$Am than for $^{239}$Pu. However, the $^{239}$Pu data probably provide the best estimate of the wound intake and dose, because there are more (and better) urine data for $^{239}$Pu than for $^{241}$Am.
Also in case 47 the assessment of intake and dose from the faecal data led to a large underestimate of the dose based on direct measurements of the lung. This raised the question of how general it was that faecal data would underestimate doses.

In case 51 evaluator E7 indicates that for a continuous intake of 1 year before the beginning of measurements the values of intake for Type S are 16, 49 and 106 kBq based on faeces, lung and urine monitoring respectively. The simultaneous use inside IMBA of the three type of monitoring permits the best estimate of 28 kBq and 176 mSv to be obtained. Also in this case the intake based on faeces resulted in an underestimate.

In case 65 Evaluator E4 indicated that he would not use the faecal data for the evaluation of $^{90}$Sr intake. His best fit evaluation, obtained by forcing the software to have an F type compound (not fitted but coherent with chemical compound), is the average of the intake values based on urine and faeces. Also considering strontium chloride as an S compound (!) as suggested by the fit, and only using the late faecal excretion data, he found that the estimate based on faeces is a factor 5 below the estimate based on urine with the same AMAD. The factor of underestimation is 4 for the CED.

In case 77 with 5 urine data, all <LOD, 8 faeces data and 1 lung data, evaluator E9 used all the types of monitoring in IMBA, considering the urine data as “<LOD”.

In case 94, the lung data were preferred to urine by evaluator E2 because it was considered that, for relatively insoluble uranium compounds, lung data should be more reliable than urine. This is due to the fact that lung dose makes the main contribution to effective dose, and assessing lung dose from urine is very sensitive to dissolution/absorption in lung. Evaluator E2 used lung data and those urine data that are before the beginning of the lung measurements.

In case 102, lung and urine data were used simultaneously by evaluator E7 to evaluate the mix of type M (85%) and type S (15%) 10 µm AMAD intake, in IMIE code. Evaluator E1 indicates that lung data are assumed to be more reliable for uranium dose assessment while urine data are useful to estimate type of absorption. His best estimate (mix of type M (80%) and type S (20%) 5 µm AMAD intake) is based on lung data.

In case 104 evaluator E1 indicates that lung data are assumed to be more reliable for uranium dose assessment while urine data are useful to estimate type of absorption. The lung measurement data set is assumed to be more reliable than the urine data for dose assessment since the body activity is directly measured. His best estimate (type M, 10 µm AMAD) is based on lung data.

In case 206 containing 11 lung data and 4 urine data, evaluator E2 using IMIE obtained with IMIE best fit for type S for lung data and type M for urine data. He considered the best fit from IMIE that derived from urine data. Evaluator E9, combines in IMBA Expert™ code lung, liver, skeleton and urine data and assumes specific absorption parameters (see paragraph 5.4).

*Indication for the guidelines:*

Consider the experience gained to indicate the proper monitoring type for the dose evaluations.

- Indicate that for $^{90}$Sr feces data are less reliable than urine data (cases 1, 26 and 65).
- The experience of case 47( mix inhalation and wound) indicates that inhalation pathway can be better evaluated by means of lung data while continuous wound uptake can be better evaluated by means of urine data.
- For relatively insoluble compounds of U, lung data should be more reliable than urine. Urine data can provide better estimation of absorption Type.
Chapter 5

Evaluating parameters

5.1 Introduction
In this chapter the main parameters of the internal dose assessment will be considered. The experience gained in the performing of the evaluations will be collated and presented by category. This will provide the basis for drafting the guidelines.

5.2 Time pattern of intake
The time pattern of intake is the main factor affecting the calculation of retention curves. If a unique intake occurs the time of intake can be a known or an unknown parameter. Also the pattern of intake, (e.g. single, repeated, chronic) can be known or unknown. It is particularly important to investigate the consequences in the dose evaluation of different but equivalent patterns of intake.

Known conditions

- Acute intake
  Examples:
  Acute inhalation of fission products as in case 1.
  Accidental injection of $^{32}$P as in case 2.
  Acute inhalation of Pu as nitrate in case 15 and 16.
  Cases 18, 19, 20, 21 and 25 connected to a single inhalation case of $^{60}$Co on 24 February 1988.
  Acute inhalation in an incident with flame sealing of ampoule of $^3$H in case 23.
  Acute intake of $^{90}$Sr in case 26.
  Acute inhalation in an incident with flame sealing of ampoule of $^3$H in case 23.
  Acute inhalation of mix of Pu and $^{241}$Am in case 31.
  Acute inhalation of Pu with 12-y follow up in case 39.
  Acute ingestion of $^{210}$Po in case 46.
  Acute inhalation and wound of mixture of Pu and $^{241}$Am in case 47.
  Acute inhalation of Sr titanate in cases 48 and 49.
  Acute inhalation of UF$_4$ (natural uranium) in case 58.
  Acute inhalation of $(^{125}$I)$_2$ as gas in case 60.
  Acute injection of $^{202}$Tl in case 64.
  Acute intake of $^3$H in case 63.
  Acute inhalation of $^{90}$Sr chloride in case 65.
  Acute inhalation of $^{75}$Zr in case 75.
  Acute inhalation of UF$_6$ in case 84.
  Acute inhalation of U$_3$O$_8$ (HEU) in case 91.
  Acute inhalation of $^{60}$Co in case 92.
  Acute inhalation of enriched U in case 104.

- Controlled experiment
  Examples:
  Chronic exposure of $^3$H with intake via skin from a wristwatch in case 6.

- Date of intake limited in an interval
  Examples:
  Acute ingestion of $^{90}$Sr limited in a 13 d period in case 7. Intake set by both evaluators at the middle of the interval (mid-point). Considering the intake at the beginning, in the middle and at the end of potential intake the
differences in the estimated CEDs are small: 56, 49, 43 μSv respectively. E4 takes the mid-point value as the best estimate.

In case 14 the intake of $^{239+240}$Pu occurred at some time between 26 October and 10 November 1969. (15-d period for the single acute intake). The monitoring interval spans for about 9000 days, up to April 1994. The exact day of intake has hardly any influence on the analysis. For evaluator E4 the best estimate is based on day 3 (29 October) the values of intake and CED are 1870 Bq and 61 mSv. The other evaluator with the same conditions (5 µm AMAD, type M) and day 0 (26 October) obtains 2130 Bq and 69 mSv.

A chronic intake lasting for a known long period of time, with measurements made during the exposure period and also after the end of exposure, is presented in case 13. One evaluator (E4) did not include those measurements performed at the end of the exposure period. In this case it is possible to check the validity of the evaluation based on continuous intake verifying that the CED value is consistent with that obtained for an acute intake set at the mid-point of the exposure period. An overestimate results for the evaluation based on an acute intake at the beginning of the exposure period and an underestimate results if the intake has been considered to occur on the last day of exposure. Also taking into account some monitoring results during the exposure period the intake values do not differ between the 2 evaluators (E4 and E7). CEDs differ due to the assumption of unique absorption type made by E4 rather than that of mixed types (E7).

- Known dates of potential intakes
In cases 40 and 43 of protracted exposures with monitoring for Pu more potential intakes (10-13) with known dates are present. Earlier intakes must be taken into account when a new incident occurs. The analysis of the data can start with this initial assumption date. Different AMAD values can be fitted to data for different periods and differ from each other. DTPA therapy was considered by evaluator E2 by excluding data for 56 days (4 half times of 14 d each).

Several potential intakes in a 16-y monitoring period for Pu are indicated in case 44. DTPA treatment was performed after the last potential date of intake. The AMAD and type of compound have been evaluated by E4. In this case the analysis of data permits consideration of an intake, that had not been identified as a potential intake in the case description, at around 1250 days after the beginning of the monitoring.

- Repeated intakes: unknown intake date inside the period
Repeated routine measurements, $^{125}$I monitoring several times in a month but not at a regular intervals in case 27. For evaluator E6, considering a series of repeated acute or chronic intakes did not change the estimated total intake and CED. Much more difference in intakes (not in CEDs) has been seen to be dependent on the chemical (methyl iodide) or physical (1 or 5 µm AMAD) form of the iodine. The same comments are reported from evaluator E1 for case 28.

For the evaluator (E1) the best estimate on case 27 is based on repeated acute intakes (inhalation) of elemental iodine.

Continuous intake due to contaminated food consumption is presented in case 9 for $^{137}$Cs contamination after the Chernobyl accident. Evaluator E6 indicated that in this case the total CEDs evaluated are not very sensitive to the length of the time period for which the intake rate is assumed to be constant. In the same case, if there are plenty of monitoring data covering a complete monitoring period the assumption of either chronic or acute intake conditions provides the same, or very close, results in assessed CED. The best estimate of the same case for evaluator E1 is based on 11 continuous intakes to take into account the increase and decrease of the intake pattern due to the changing level of contamination in food.

In case 5 (routine monitoring for Pu of a worker operating near a glove box for 10 years) there are only 7 out of a total of 29 data points which are above the minimum detectable activity (Limit of Detection, LOD). The evaluator E1 has doubt in considering the pattern of intake to be really chronic or a sum of several acute intakes. The doses in this case are significantly different: 192 mSv for chronic inhalation, 284 mSv for repeated acute inhalations.
In case 106 (routine measurements of thyroid for 2 y and 9 months exposure for a worker in a radiopharmaceutical industry) the evaluator E1 considers a series of repeated acute intakes using the ICRP 78 pattern of intake for routine monitoring. The same pattern of intake has been assumed by evaluator E3 for case 22 of $^3$H exposure.

**Unknown conditions**

- **Chronic with unknown beginning:**
  In case 51 related to chronic inhalation of HEU a complete set of data related to lung, urine and feces is available. The data show a decreasing behavior beginning at the date of removal of the subject from the exposure. The beginning of the exposure period is not known. Evaluator E7 arbitrarily chooses a period of 1 year before the removal of the subject from work as the date of beginning of exposure.

- **Unknown intake dates**
  Unknown intakes can be identified by fitting the measured data. As indicated above, in case 44 an incident probably occurred at 1250 days and it was not indicated in the case description as a potential intake.

In case 94 lung and urine data over long periods of times are available. Evaluator E2 standardized the so-called “estimated annual excretion” on the basis of daily mean concentration, 1.4 Bq/L factor and 365 d/y value. Several acute intakes have been assumed.

- **Mixed pattern of intake**
  The description of case 30 indicates 2 potential dates of intake for a worker exposed to both $^{239}$Pu and $^{238}$Pu. Two acute and a chronic intake were considered by evaluator E1 for $^{239}$Pu. Different AMAD values were assumed (with the help of the fitting software) ranging from 0.1 to 5 µm for the 2 acute intakes and 15 µm for the chronic intake. The assumed absorption type is M for the acute intakes and S for the chronic intake. More than 92% of the total dose is due to the chronic intake lasting for 1100 days.
  For $^{238}$Pu in the same case, evaluator E2 assumed only two acute intakes at different dates from the previous ones with the first intake representing almost all the intake.

Continuous intake for 10 years and some acute intakes during the last year were assumed by Evaluator E3 in case 91 for enriched uranium.

**Indication for the guidelines:**
Consider the experience gained during performance of the evaluations to suggest a default approach of assessment in absence of information related to time pattern of intake, especially in case of repeated routine measurements.

**5.3 Pathway of intake** (mixed paths)
Inhalation is the most important pathway of intake related to the evaluated cases. In other situations the case description permits the correct identification of the pathway. The case description scenario and the complementary data (Static Air Samplers for inhalation, hand surface contamination for ingestion, etc.) give help in correct identification. So the general information is outside the monitoring dataset.

In some other cases the fitting software can help in evaluating the presence of another pathway. It is the case of ingestion in presence of inhalation. This has been experienced in cases 48 and 49. In these cases during handling of a defective waste container with an old source of $^{90}$Sr a worker monitored himself and found a positive response: serious extensive surface contamination was found. A nose-swab was taken and also provided positive results. So in principle it is possible in this case scenario to have both intake regimes. One of the evaluators (E7) considered the possibility of having both inhalation and ingestion. A trial and error exercise, using the embedded
retention functions of IMIE, and an evaluation with IMBA using 2 intake regimes, indicated intakes of 70% ingestion and 30% inhalation.

Another example of mixed path of intake is presented in case 47. The case description indicates that during some operations of filling the sintering furnace inside glove box No. 27 with an argon-hydrogen (6%) mixture, an explosion occurred. The person near the glove box was injured on his right cheek by fragments of the window. The wound on the cheek was 3 x 0.5 cm. The person also showed diffuse contamination on the hair and a considerable activity in the nose which indicates a possible intake by inhalation. The analysis of this complex case performed by one evaluator (E2) aimed at reconciling the lung and feces data using particle transport parameters so far as possible, on the basis of type S absorption.

A multi-step evaluation for the inhalation pathway was performed: (1) adjustment of the alveolar-interstitial (AI) fractions (set AI2/Al=0.9 and Al1 =0). (2) Set Al2=0.1 and Al3 = 0.9 with default rates 10^{-3}/d and 10^{-4}/d. (3) Remove slow tracheo-bronchial (TB, i.e. bronchial and bronchiolar) clearance, and set transfer rates bb_{2} to BB_{1} to 2/d and BB_{2} to ET_{2} to 10/d. (4) Increase the speed of gastro intestinal tract (GIT) transport by a factor of 2.5. With these corrections the urine measurements remained underestimated. Since the evaluator was not able to combine acute inhalation with chronic wound in the software, it was assumed for simplicity that all Pu in urine came from the wound. In an advanced evaluation with IMBA Expert™ a wound intake regime was introduced (as chronic for 50 y, at rate 0.0001 /d, same as slow dissolution rate s_{s} for Type S) and data were selected avoiding the early urine data (affected by DTPA treatment).

**Indication for the guidelines:**
Consider the experience gained especially to evaluate mixed paths of intake.

### 5.4 Absorption Types (mixed Types)

The experience gained by evaluators is related to the adaptation of a specific Type of absorption, when possible, to the subject data. The first step is to use the ICRP default option, then try a mixture of Types (especially M and S), then try to change the long-term component of absorption e.g. as required by a super-S compound.

**Choice of type**

In case 1 evaluator E7 uses, for the inhalation of graphite with fission products, Type F behavior for $^{137}$Cs based on WB measurements, based on the general indications for the radionuclide, but Type S behavior for the $^{90}$Sr based on urine excretion data, which is only indicated for Sr titanate. Type F behavior for $^{90}$Sr does not fit the data.

In case 5 for chronic intake of $^{239}$Pu with a large set of data < LOD, and in case 11 of accidental intake of the same radionuclide, evaluator E1 uses absorption Type S.

Case 12 is related to a reconstruction of an old exposure of $^{239}$Pu with no initial $^{241}$Am intake and the availability of several data sets (lung, urine, faeces, liver and skeleton). Many data are < LOD. The analysis is based on evaluation using at the same time all the available data sets and the maximum likelihood method (via the IMBA code). Regarding the absorption parameters related to the Type of compound evaluator E9 indicates that the material was detectable in the lung at about 9000 days; so the material must be relatively insoluble. Also better agreement between the predictions and the data is obtained assuming Type S compared with Type M. Thus, he initially assumes Type S. The fits to the data sets assuming Type M are always worse.

A second assessment was based on specific absorption parameters. The estimated intake from the urine data alone is less than that from the faecal data alone by a factor of 2.4. Also the predicted faecal excretion arises mainly from material cleared from the lung (75% of excretion). So to obtain better agreement between intakes estimated from the urine and faecal data the model needs to predict lower urine excretion rates and higher faecal excretion rates at later times. This can be achieved by making the material more insoluble. Thus the evaluator E9 decreased the slow dissolution rate s_{s} from $1.10^{-4}$ to $5.10^{-5}$ d$^{-1}$. Thus with the absorption parameters values in Table 5.1 the intake of $^{239+240}$Pu is 23 kBq.
resulting in a dose of 228 mSv. Data reported as < LOD was entered flagged as “<LOD”. The estimated intake from the urine data alone is now less than that from the faecal data only by a factor of 1.13 (i.e. only a 13% difference). However, the fit to the lung data could be improved by reducing particle transport rates.

Table 5.1 Comparison of the specific HRTM parameter values in second assessment with default values

<table>
<thead>
<tr>
<th>Absorption</th>
<th>Fitted</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_r$</td>
<td>0.001</td>
<td>1.0</td>
</tr>
<tr>
<td>$s_{e}$ (d$^{-1}$)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>$s_{s}$ (d$^{-1}$)</td>
<td>$5 \cdot 10^{-5}$</td>
<td>$5 \cdot 10^{-3}$</td>
</tr>
<tr>
<td>$f_b$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$s_{b}$ (d$^{-1}$)</td>
<td>$1 \cdot 10^{-4}$</td>
<td>$1 \cdot 10^{-4}$</td>
</tr>
</tbody>
</table>

A third assessment was based on specific absorption and particle transport parameter values. The retention in the lung was increased by evaluator E9 by reducing the particle transport rate ($AI_3 \to bb_1$) from $1 \cdot 10^{-4}$ to $5 \cdot 10^{-5}$. This had the effect of increasing lung retention, increasing activity in urine and decreasing activity in faeces. To decrease systemic urine and faecal activity the absorption rate $s_s$ was decreased to $3 \cdot 10^{-5}$. The fits to the data with these parameter values (Table 5.2) are shown below. The overall $\chi^2$ is now better than in the previous two cases indicating the reaching of a best fit. The final estimated intake is 29.1 kBq of $^{239+240}$Pu and the resulting dose is 299 mSv.

Table 5.2 Changed parameters on third assessment

<table>
<thead>
<tr>
<th>Absorption</th>
<th>Fitted</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s_{e}$ (d$^{-1}$)</td>
<td>$3 \cdot 10^{-5}$</td>
<td>$5 \cdot 10^{-3}$</td>
</tr>
<tr>
<td>Particle transport rate</td>
<td>$AI_3$ to $bb_1$ (d$^{-1}$)</td>
<td>$5 \cdot 10^{-5}$</td>
</tr>
</tbody>
</table>

In case 14 both evaluators (E2 and E4) indicate Type M (based on urine data). Teeth long term measurements give an indication of ingrowth of $^{241}$Am from $^{241}$Pu.

In cases 18, 19, 20, 21 and 25 the Type of compound is mainly M. Both evaluators give this indication based on the fitting of the data.

In practice there is no possibility to make the choice of Type for inhalation of iodine aerosol compounds (as in case 27) as they are always Type F. In this case it is possible to make the choice between elemental iodine or organically bound iodine inhalation. Evaluator E1 chose elemental iodine in case 27. The other evaluator E6, chose a mixture (see below).

In case 29 (acute inhalation of $^{192}$Ir) both evaluators (E2 and E6) used Type S as indicated by whole body measurements in the different working places.

In case 30 different absorption Types (M and S) were assumed by evaluator E1 for the accidental inhalations of the subject in the different workplaces.

In case 31 an inhalation of Type S was considered by the evaluator E2. Case 31, the Swiss case, has been also used in ICRP Guidance Document 3 to illustrate an example of a retrospective assessment, for which the data were not consistent with the behaviour predicted by the HRTM with its default parameter values. However, a reasonable fit to the $^{241}$Am in lung, urine and faeces could be obtained by adjusting certain parameter values.
The NRPB program GIGAFIT\textsuperscript{20} was used to estimate the intake of $^{241}\text{Am}$ such that the predicted lung retention and urinary and faecal excretion rates fitted the $^{241}\text{Am}$ data. A simplified version of the HRTM was implemented in GIGAFIT.

Absorption-to-blood parameters: $f_r$ and $s_r$ were varied. The value of $s_r$ was fixed at its default value of 100 d\(^{-1}\), because there are few early data available to determine it. The absorption to blood parameters for the bound state were fixed at values determined experimentally for $^{241}\text{Am}$ nitrate: $f_b = 0.87$ and $s_b = 0.15$ d\(^{-1}\).

Particle transport parameters for the AI region: the fraction of the AI deposit cleared relatively rapidly, AI$_1$/AI, (default value 0.3), and the clearance rate from region AI$_2$ to the TB region (default value 0.001 d\(^{-1}\)) were reduced to model the long-term lung retention. The fraction AI$_3$/AI was fixed at its default value of 0.1 and therefore AI$_2$/AI was given by (0.9 – AI$_1$/AI).

The specific parameter values obtained are as follows. The fraction absorbed rapidly $f_r = 0.0073$ is intermediate between Type M (0.1) and Type S (0.001) default values. The slow dissolution rate $s_s= 0.000048$ d\(^{-1}\) is similar to that for Type S (0.0001 d\(^{-1}\)), but even slower. The fitted fraction of the AI deposit that cleared relatively rapidly (AI$_1$/AI), was reduced to a much lower value (0.9\%) than the default value (30\%), as was the rate of clearance from AI$_2$ (2.0 \(10^{-4}\) d\(^{-1}\), compared to the default value of 1.0 \(10^{-3}\)) d\(^{-1}\).

As a further step in the evaluation, to reduce the faecal excretion at later times, the particle transport from lungs (alveolar region) was reduced. For simplicity, default clearance rates from the 3 alveolar compartments AI$_1$, AI$_2$ and AI$_3$ (0.03, 0.001, 0.0001 d\(^{-1}\)) have been retained and only the fractions were varied. AI$_1$ was already reduced from its default value of 0.3 to 0.008, it was reduced further to 0.0. The fraction in AI$_3$ was increased from 0.1 to 0.8. This provided a good fit.

In the same case 31 the $^{239}\text{Pu}$ parameter values were also set to those of $^{241}\text{Am}$. In particular, in fitting the urine and faeces data simultaneously, the particle transport from lungs was reduced in line with that for $^{241}\text{Am}$. So the default clearance rates from the 3 alveolar compartments AI$_1$, AI$_2$ and AI$_3$ (0.03, 0.001, 0.0001 d\(^{-1}\)) were retained and the fractions varied. The fraction in AI$_1$ was reduced from its default 0.3 to 0.0. The fraction in AI$_3$ was increased from 0.1 to 0.8.

The dissolution parameter values obtained for $^{241}\text{Am}$ were also applied. The slow dissolution rate was reduced from the Type S default (0.0001 d\(^{-1}\)) to 0.000048 d\(^{-1}\) and the rapid dissolution fraction was increased from Type S default (0.001) to 0.0073. Also in this sub-case this gave a good fit.

In case 39 the comparison of fitting using Type M and S gives a clear indication that the right Type is M (as stressed by evaluator E4). The other evaluator E2 tried to fit with Type S but the fit is worse than with Type M. In this case Evaluator E2 uses also transfer specific parameters based on Pu nitrate and introducing the bound state basis on rat data ($f_b=0.57$ and $s_b=0.21$). He also changed $f_r=0.04$ (default value = 0.1) and $s_s = 0.1$ d\(^{-1}\) (default 0.005 d\(^{-1}\)); the changing of $s_s$ has little effect on evaluated CED.

In case 40 of several acute inhalations of $^{239}\text{Pu}$ (up to 10 potential contamination incidents) over 17 years evaluator E4 let the IMIE code in semi-automated mode choose the best fit between Types M and S. At the end of the analysis he chose Type S and 5 µm AMAD to evaluate 7 acute intakes (maximum 1\textsuperscript{st} and 6\textsuperscript{th} with 60 - 65 mSv each). Total intake = 22.6 kBq, total CED = 187 mSv. The other evaluator (E2) used only Type M and 5 µm AMAD in IMIE code to evaluate 7 acute intakes with the 1\textsuperscript{st} representing more than 80\% of total intake (1190 Bq) ad total CED = 38 mSv. In this case the choice of Type makes an important difference to the total evaluated CED (about a factor of 5).

In case 43 (several intakes of $^{239}\text{Pu}$ with a DTPA treatment) evaluator E4 indicates 7 intakes with different AMAD values and Types (3 intakes M and 4 intakes S). Total intake =28.3 kBq, total CED = 168 mSv (156 mSv for type S and 12 mSv for type M). The other evaluator (E2) considering always Type M (also in this case allowing the AMAD to vary) provides total intake =1.4 kBq and total CED = 38 mSv. In this case too, the choice of Type makes an important difference to the total evaluated CED.

For a very long monitoring period (such as 16 years in case 44) it is not logical, as indicated by evaluator E4, to consider always the same compound involved in repeated intakes of personnel and consequently permitted the absorption Type to change. In this case the fitting can help in make correct evaluation of absorption Type.
In case 47 (inhalation + wound) Type S was used by evaluator E2 for inhalation and the slow dissolution rate of Type S, \( s_s = 0.0001 \text{ d}^{-1} \) was used as the rate of chronic intake via wound.

In case 48 for acute inhalation of \(^{90}\text{Sr}\) titanate evaluator E4 considered Type S and let the AMAD vary. For 20 \( \mu \text{m AMAD (best estimate)} \) he evaluated 980 kBq and CED = 11.4 mSv. The other evaluator E7 considered 72% ingestion and 28% inhalation (Type S and 10 \( \mu \text{m AMAD} \)). For inhalation he evaluated 131 kBq and 4.66 mSv; ingestion represented 338 kBq and 0.9 mSv.

The same situation is present in case 49 with 2 <LOD data: Evaluator E4, Type S, 20 \( \mu \text{m AMAD, Intake} = 230 \text{ kBq, CED} = 2.7 \text{ mSv using LOD/2 value for <LOD data. Evaluator E7 found the same percentages 72% ingestion and 28% inhalation (Type S and 10 \( \mu \text{m AMAD} \)). Total intake 91 kBq; total CED} = 1.09 \text{ mSv.}

In case 51 of chronic intake of HEU with unknown date of beginning of exposure, the values of type S parameters based on compound U\(_3\)O\(_8\) have been used by evaluator E7.

In case 58 with accidental inhalation of UF\(_4\), the behavior of urine measurements presents an increase with a maximum at 60 days after the incident with a return to background level at about 1000 days after it. Material specific absorption parameter values have been derived from the results of several experiments in which uranium tetrafluoride was administered to the lungs of rats \(^{21}\). For this case evaluator E2 took rounded central values of \( f_r = 0.5, s_r = 0.15 \text{ d}^{-1} \) and, \( s_s = 0.005 \text{ d}^{-1} \).

A limitation of the HRTM formulation to represent time-dependent dissolution using \( f_r, s_r \), and \( s_s \) is that it can only represent an overall fractional dissolution rate that decreases with time. To overcome this, the HRTM uses an equivalent system with the same number of variables, but which gives greater flexibility. In this, the material deposited in the respiratory tract is assigned to compartments labelled “Particles in initial state” in which it dissolves at a constant rate \( s_p \). Material is simultaneously transferred (at a constant rate \( s_{pt} \)) to a corresponding compartment labelled “Particles in transformed state” in which it has a different dissolution rate, \( s_t \). With this system, the initial dissolution rate is approximately \( s_p \) and the final dissolution rate is approximately \( s_t \). Thus with suitable choice of parameters, including \( s_t > s_p \) an increasing dissolution rate can be represented. The ratio of \( s_p \) to \( s_{pt} \) approximates to the fraction that dissolves rapidly. Eventually the absolute rate decreases as the lung content does.

If the dissolution rate decreases with time, as is usually the case, either system can be used, and gives the same results, with the following values:

\[
s_p = s_s + f_r (s_r - s_s); \quad s_{pt} = (1 - f_r) (s_r - s_s); \quad s_t = s_s
\]

This approach has been used to simulate the increasing dissolution of \(^{238}\text{PuO}_2\) by James and co-workers \(^{22}\) with \( s_p = 10^{-6} \text{ d}^{-1}; s_{pt} = 0.00189 \text{ d}^{-1}; s_t = 0.000257 \text{ d}^{-1}\).

In the case 58 it is difficult to obtain a sharp enough peak. However, parameters have been set to model the increase of excretion in the following way: \( f_1 = 0.0002; s_p = 0.000200 \text{ d}^{-1}; s_{pt} = 0.02 \text{ d}^{-1}; s_t = 0.04 \text{ d}^{-1}\). (Note \( f_1 \) was also reduced to reduce early excretion.)

This was done without using the bound state since evidence suggests no significant “binding” of uranium. Use of the bound state could significantly increase the dose, and it should not be applied arbitrarily. It may be possible to improve the fit further, but no systematic basis is currently available. The best fit to the data was reached using those parameters.

In case 65 of an acute intake of strontium chloride (indicated as type F compound) there are urine and feces data available. The best estimate made by evaluator E4 indicates as best fit an inhalation of Type S, 10 \( \mu \text{m AMAD} \) aerosol. Forcing to take type F and 5 \( \mu \text{m AMAD} \) results in an intake an order of magnitude less than that related to Type S. The fit is worse and urine data are not fitted for values greater than 200 days post-incident. Also the feces data are not fitted. The evaluator E4 indicates that the data fitting and Type of compound are conflicting.

In case 75 for incidental inhalation of \(^{75}\text{Zr}\) carbide both evaluators (E3 and E7) used Type S in accordance with the compound.
In case 77, Evaluator E9, as the urine measurements are all below the LOD, considered that the $^{241}$Am compound is probably insoluble, and so assumed Type S. Specific parameters were then changed (reduction of $f_r$ and $f_1$) (see Table 5.3) to obtain a best fit of intake of 157 Bq, resulting in an effective dose of 1.32 mSv. All the data were used, flagging the < LOD data as “<LOD” in the IMBA code.

Table 5.3 Comparison of the specific HRTM parameter values with default values. (Case 77)

<table>
<thead>
<tr>
<th>Absorption</th>
<th>Specific $^{241}$Am</th>
<th>Default Type F</th>
<th>Type M</th>
<th>Type S</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_r$</td>
<td>$1.0 \times 10^{-4}$</td>
<td>$1.0$</td>
<td>$0.1$</td>
<td>$1.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>$s_r$ (d$^{-1}$)</td>
<td>$100$</td>
<td>$100$</td>
<td>$100$</td>
<td>$5 \times 10^{-3}$</td>
</tr>
<tr>
<td>$s_s$ (d$^{-1}$)</td>
<td>$1 \times 10^{-4}$</td>
<td>–</td>
<td>$5 \times 10^{-3}$</td>
<td>$1 \times 10^{-4}$</td>
</tr>
<tr>
<td>$f_b$</td>
<td>$0$</td>
<td>$0$</td>
<td>$0$</td>
<td>$0$</td>
</tr>
<tr>
<td>$s_b$ (d$^{-1}$)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$f_1$</td>
<td>$1.0 \times 10^{-5}$</td>
<td>$5.0 \times 10^{-4}$</td>
<td>$5.0 \times 10^{-4}$</td>
<td>$5.0 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

In case 84 incidental inhalation of UF$_6$ both evaluators (E2 and E3) used type F in accordance with ICRP guidance for most hexavalent uranium compounds.

In case 91, related to accidental inhalation of enriched uranium in the form of U$_3$O$_8$, with only 10 lung data available for $^{235}$U ($^{234}$U gives the highest CED probably 29 times that of $^{235}$U) evaluator E2 considers the possibility to have Type M or S and specific parameters of U$_3$O$_8$. It turned out that the best fit for 5 µm AMAD is related to Type M. Also considering the mean values of $f_r = 0.04$, $s_r = 1$ d$^{-1}$ and $s_s = 0.001$ d$^{-1}$ based on 3 recent papers and related to in vivo studies of U$_3$O$_8$ and applying them to the case, the fit is not considered as good as that related to Type M. The other evaluator E3 uses Type S, and chronic + spot acute intakes. The intake and CED evaluations are not comparable between the two evaluators due to the different applied methodologies.

For case 92 related to acute inhalation of $^{60}$Co, both evaluators (E5 and E6) allowed the absorption Type to be evaluated by fitting the data, and as a final result indicated as best fit that provided by Type M. The final Intake and CED are similar for both evaluators (same order of magnitude with differences only on the AMAD value).

In case 94 related to routine monitoring of U due to protracted exposure, a better agreement between lung and urine data for Type M compound than for Type S, was found by evaluator E2 and a better fit to lung data. Also he presented the consideration that Type M for U seems to be more likely than Type F or S as more compounds in nuclear fuel production are related to that absorption Type.

In case 104 related to accidental inhalation of enriched uranium, evaluator E1 considers lung data more reliable for dose assessment. A Type M with 10 µm AMAD provide the best fit.

In case 206 with accidental inhalation of $^{241}$Am (11 lung measurements, 11 skeleton measurements, 11 liver measurements and 4 urine measurements available) evaluator E9 using IMBA tried to fit simultaneously the data having as indication of goodness of fit the value of the $\chi^2$ calculated for values above LOD (all data). This permits comparison of results using different values of HRTM parameters. No indication for AMAD can be found from the data so the default 5 µm was assumed. Evaluator E9 performs a multi step evaluation. The first step is related to the choice of absorption Type. As default ICRP 68 recommends Type M for $^{241}$Am. In contrast, the lung retention data suggest that the material is Type S rather than Type M. Assuming Type S and simultaneously fitting the lung, liver, skeleton and urine data shows that the fits to the liver, skeleton and urine data are poor. The model predictions are much lower than the data, with an overall $\chi^2 = 247$. For comparison purposes the fits for a Type M material are attempted. There is a poor fit to lung, but much better fits to liver, skeleton and urine, with an overall $\chi^2 = 122$.

Second step: absorption parameter values were varied to increase the amount of material initially absorbed from the lung to blood. As there are no early data (< 48 d) the rapid dissolution rate, $s_r$ cannot be determined. So the
parameter $s_r$ was fixed at its default value of 100 d$^{-1}$ and the values of $f_r$ and $s_s$ were varied by “trial and error” (iteratively) until a reasonable fit was obtained. However, note that $f_r$ predominately affects the fit to the skeleton and liver data at early times, and $s_s$ predominately affects the fit at mid to later times (Table 5.4).

Table 5.4 Comparison of the specific HRTM parameter values with default values

<table>
<thead>
<tr>
<th>Absorption</th>
<th>Fitted</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_r$</td>
<td>0.05</td>
<td>1.0</td>
</tr>
<tr>
<td>$s_r$ (d$^{-1}$)</td>
<td>100 (fixed)</td>
<td>100</td>
</tr>
<tr>
<td>$s_s$ (d$^{-1}$)</td>
<td>5. 10$^{-4}$</td>
<td>5. 10$^{-3}$</td>
</tr>
<tr>
<td>$f_s$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$s_b$ (d$^{-1}$)</td>
<td>0</td>
<td>5. 10$^{-4}$</td>
</tr>
</tbody>
</table>

The overall $\chi^2$ of the fit is 45: much lower than for Type M or Type S.

Step 3: specific absorption and particle transport parameter values
Liver, skeleton and urine fits are better. However, the fit underestimates the long-term lung retention data. Thus to improve the fit to the lung data evaluator E9 needed to reduce the clearance from the AI region by varying the longer-term particle transport rates. The HRTM represents the AI region by 3 compartments, (AI$_1$, AI$_2$ and AI$_3$). Variation in the overall retention in AI can be achieved by varying either the amount in each compartment or the clearance rate from each compartment. ICRP Publication 66, paragraph E218, page 381 suggests that the particle transport rates from AI$_2$ to bb$_1$ and from AI$_3$ to bb$_1$ and the fraction AI$_1$/AI are treated as variables whereas the fraction AI$_3$/AI is fixed at its default value of 0.1. Thus AI$_3$/AI is given by (0.9-AI$_1$/AI). Paragraph E4, page 304 of ICRP Publication 66 suggests that the inter-subject variation in any clearance rate can be represented by a lognormal distribution with a median ($X_{50}$) equal to the reference value and a $\sigma_v$= 1.7. This gives 95% confidence limits at $X_{50}/3$ and 3*$X_{50}$. Thus evaluator E9 reduced the rate from AI$_2$ to bb$_1$ by a factor of 3 to increase the long-term retention (Table 5.5). Reducing AI$_3$ to bb$_1$ will have little effect as the slow dissolution rate $s_s$, at 5. 10$^{-4}$, already dominates clearance from compartment AI$_3$.

In this case better fits (lower $\chi^2$) were obtained by varying the rate AI$_2$ to bb$_1$ rather than the ratio AI$_1$/AI.

Although fit improved, little effect on intake or dose (< 17%).

Table 5.5 Comparison of the specific HRTM parameter values with default values

<table>
<thead>
<tr>
<th>Particle transport</th>
<th>Fitted</th>
<th>Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractions (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AI$_1$/AI</td>
<td>30 (fixed)</td>
<td>30</td>
</tr>
<tr>
<td>AI$_2$/AI</td>
<td>60 (fixed)</td>
<td>60</td>
</tr>
<tr>
<td>AI$_3$/AI</td>
<td>10 (fixed)</td>
<td>10</td>
</tr>
<tr>
<td>Rates (d$^{-1}$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AI$_1$ to bb$_1$</td>
<td>0.02 (fixed)</td>
<td>0.02</td>
</tr>
<tr>
<td>AI$_2$ to bb$_1$</td>
<td>3.3 10$^{-4}$</td>
<td>1. 10$^{-3}$</td>
</tr>
<tr>
<td>AI$_3$ to bb$_1$</td>
<td>1. 10$^{-4}$ (fixed)</td>
<td>1. 10$^{-4}$</td>
</tr>
</tbody>
</table>

Step 4: Specific bound state parameter values.
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, Section E7.3.2.). It is emphasised that this is only an interim assessment of the extent of americium binding. These were applied to Case 31, in which an improved fit to the urine data at early times was obtained.

In this case the estimated intake and dose hardly change. No significant effect.
Step 5: lung data corrected

Chest measurements
The lung data were reduced, as the chest measurements were not corrected for contributions from activity in liver or skeleton. Kathren et al. (who published the case description) estimated that the activity in liver and skeleton would reduce lung activity by 10 to 20%. The percentage of the measured activity in the chest due to activity in skeleton and liver increases with time because the lung activity decreases and the liver and skeleton activities increase with time. Thus chest measurements were reduced by evaluator E9 by:

- 10% for data between days 47 and 200
- 15% for data between days 200 and 500
- 20% for data between days 500 and 2200

A 25% relative error pattern with normal distribution was assumed.

Liver and skeleton data
A 25% relative error pattern with normal distribution was assumed.

Urine data
As described in section 4: Assumed a lognormal distribution with a geometric standard deviation of 1.8. Sample collection time was 0.5 d.

Using all the parameters and uncertainties indicated the best fit provides these values of estimated intake = 7.2 kBq and of CED =116 mSv.

Mixed types
In case 13 evaluator E4 assumed absorption Type S. It is stated that identical parameters must be maintained in the same case scenario for all the isotopes of the same element U (234, 235 and 238). However, the possibility to have different absorption Types when different elements are involved in the same case scenario must be considered.

Evaluator E7 considered mixed Type M and S compounds for the same case 13. The percentages of absorption Types evaluated in the case of $^{234}$U (35% M + 65% S) were applied to the other isotopes of U.

In case 18 evaluator E5 indicated a mix with 95% Type M + 5% Type S and small AMAD. This was performed by letting the different percentages change between 0% and 100%.

In case 25 the best fit was found by evaluator E6 by using 80% Type M + 20% Type S.

In case 27, two phases of inhalation were assumed by evaluator E6: Aerosol (5 µm AMAD, F) 50% and Methyl-iodide vapor 50%.

In case 102, considering $^{234}$U in accidental inhalation of enriched uranium (available urine and lung data) with a value of AMAD equal to 8 µm, both evaluators (E1 and E7) provide final estimates as a mixture of 2 Types: for evaluator E1: 80% M + 20% S, AMAD = 5 µm; for evaluator E7: 85% M + 15% S, AMAD = 10 µm. Both evaluators performed a trial and error process between the types: E1 considering steps of 10% from 0% M to 100% M, E7 refining the study in the range 70% M – 90% M. “Relative distance” is the metric for the evaluation in the IMIE code to consider the goodness of the fit. CED values are similar (131 vs. 142 mSv, E1 vs. E7) even if the intake differs due to AMAD evaluation (40 kBq (5 µm) vs. 79 kBq (10 µm), E1 vs. E7).

Indications for the guidelines:
- Consider the experience gained during performance of the evaluations to suggest a default approach in the absence of information related to the compound absorption type.
- Consider the indications on compound specific parameters such as those for U, presented in ICRP Supporting Guidance 3 [18] and in report NRPB-W22 [24].
- In case of repeated intakes, guidelines must indicate if identical absorption Type for each intake or different Types can be assumed.
Consider the experience gained during the performance of evaluations and provide advice either to follow the ICRP indication on compounds specific absorption type or prefer the indication of the fitting of measured data (cases 1 and 65).

Discuss, in the guidelines, the possibility in the same case scenario of different types of compounds for different elements as in case 1. (Type F for $^{137}$Cs and Type S for $^{90}$Sr).

As gained from the experience of evaluator E9 a 5-step approach, with increasing complexity, in fitting procedure to evaluate properly the behavior of the compound can be stated.

- try to find the best fitting using one out of 3 absorption Types of compounds (F or M or S).
- consider a mixture of Types and evaluate the percentages of them on the basis of a goodness of fit metric.
- change absorption parameter values on the basis of in vivo experiments such as $f_r = 0.04$, $s_r = 1 \, \text{d}^{-1}$ and $s_s = 0.001 \, \text{d}^{-1}$ in case 91.
- consider also using $f_b$ and $s_b$ for bound state if necessary, as in case 31 for $^{241}$Am nitrate.
- change fractions of mechanical transfer as AI1/AI in case 31 or transfer rates as the rate AI3 -> bb1 in case 12.

5.5 AMAD (mixed AMAD values)
A review of the evaluations for inhalation will be presented in the present paragraph to indicate the choices performed by evaluators following the indication reported in the case description scenarios. When no information on AMAD is provided and no indication from fitting can be drawn the default AMAD parameter value is usually assumed.

Default AMAD value of 5 µm
In absence of specific information the evaluators have chosen 5 µm as default AMAD in the following cases.
In case 12, in absence of indication of any particle size, a 5 µm AMAD has been assumed:
- Case 13 by evaluators E4 and E7.
- Case 14 by evaluators E2 and E4.
- Case 15 and 16 by evaluator E2: it was stated that the evaluator is not likely to be able to estimate AMAD.

In cases 27 and 28 for chronic intake of $^{125}$I evaluator E6 used a mixture of Aerosol (5 µm AMAD, F) 50% and Methyl-iodide vapor 50%.

In case 31 the default value of 5 µm AMAD has been used by evaluator E2 for the evaluation of the “Swiss case” as the ratio between the cumulative faeces excretion in the first three days and the lung content at day 3 indicates a value of 6 µm AMAD. The figure E6.1 of Annex E of ICRP Supporting Guidance 325 has been used. Assuming AMAD either 4.5 or 6 µm AMAD has negligible effect on the dose (< 0.2%).

In case 40 both evaluators (E2 and E4) use the default 5 µm AMAD but, as indicated above, it is the choice of the absorption Type that determines substantial differences in the evaluation.

In case 51 a default values of 5 µm AMAD has been used by evaluator E7 in absence of possibility of fitting.

Also in the case 58 of accidental inhalation of UF4 natural uranium a 5 µm AMAD has been assumed by evaluator E2.

In case 77 the ratio between the cumulative faeces from day 1 to day 3 divided the lung measurement at 0.1 day for $^{241}$Am provides the indication of a 5 µm AMAD aerosol by means of the curve of figure E6.1 of Annex E of ICRP Supporting Guidance 3. This has been assumed by evaluator E9.

In case 84 evaluator E2 used the default 5 µm AMAD value due to the impossibility to fit particular value of AMAD. The other evaluator E3 provides evaluation for 0.3 µm AMAD.
In case 91, evaluator E2 provides results for 5 µm AMAD while the other E3 indicates 0.001 µm. The intakes differ for a factor of 3 and the CEDs for a factor of 2.

Also in case 92 of acute exposures of $^{60}$Co the two evaluators provide different results. Evaluator E5 gives result for 5 µm AMAD, Type M (intake = 13.2 kBq CED= 94.4 µSv), while evaluator E6 provides evaluation for 20 µm AMAD, Type M (intake = 45.1 kBq CED= 132 µSv).

No indication for choice of AMAD was given by evaluator E2 in case 94 so default 5 µm AMAD has been used.

In case 102 both evaluators (E1 and E7) used a mix of absorption Types: E1 with default 5 µm AMAD while E7 with 10 µm AMAD. The results of CEDs are comparable to each other.

**Other AMAD values**

In case 1 the evaluator E7 used AMAD = 1 µm based on fitting of $^{137}$Cs in WB measurements. The same AMAD was also applied to $^{90}$Sr.

In case 5, for chronic exposure of $^{239}$Pu evaluator E1 found as best fit (based on relative distance of IMIE) an AMAD of 0.03 µm.

In case 11 evaluator E1 keeps as best estimated intake the mean value of the manual evaluations on the urine and faeces datasets that provide the best estimates for different AMAD values: 20 µm urine, 0.1 µm faeces. The average of the two intakes has been used as best estimate. Consider to give advice in the guidelines.

In case 18 the evaluator E5 gives the indication of 0.01 µm based on IMIE fit. Also the other evaluator E6 indicates the good fit obtained with 0.01 µm AMAD but considering the other subjects related in the same case scenario (cases 19, 20, and 25) for which the 1 µm AMAD provides the best fit, he chose to assume the same 1 µm AMAD also in case 18. For case 21 evaluator E6 assumes 5 µm AMAD based on realistic evaluation of fit (small diameter component has been neglected in the best fit that provides 75% 5 µm AMAD type M + 25% 0.003 µm AMAD type S).

For cases 19, 20, 21 and 25 evaluator E5 gives the indication of 1 µm AMAD

In case 29 evaluator E2 uses 8 µm AMAD as considered the best fit (54 kBq, 0.18 mSv). For the same case evaluator E6 indicates 3 µm AMAD (25.2 kBq, 0.155 mSv).

In case 30 evaluator E1 considers several AMAD values from 0.1 to 15 µm for the different acute intakes assumed during the monitoring of the worker.

In case 39 using the IMIE code, both evaluators E2 and E4 indicate 0.1 µm AMAD as best fit: intake and CEDs are comparable (4.2 kBq and 480 mSv for E2, 3.8 kBq and 439 mSv for E4).

In case 47 (inhalation + wound) the evaluation of AMAD performed by E2 is based on the ratio of cumulative faecal excretion (days 1 to 3) to lung retention on day 3. The indication is of 10 µm for $^{241}$Am and 7 µm for $^{239}$Pu, and 8.5 µm was taken as a mean value for both radionuclides.

In cases 48 and 49 evaluator E2 considers as best fit 20 µm AMAD as the fitted AMAD = 0.001 µm is not considered to be realistic. The other evaluator E7 indicates 10 µm AMAD for the part of intake related to inhalation (ingestion also present).

In case 65 also the choice of the AMAD equal to 10 µm (instead of 5 µm) together with the absorption Type (S instead of F) determines the difference in dose evaluation for Sr chloride showing Type S behaviour (16.7 mSv (10 µm, S), instead of 0.184 mSv (5 µm, F) as evaluated by E4.)
In case 75 the best estimate of evaluator E7 performed with the IMIE code indicates a 0.3 µm AMAD. The other evaluator E3 provides evaluation with 0.03 µm AMAD. The CEDs are comparable but obviously the intakes are more than a factor 3 different each other.

In case 104 an AMAD = 10 µm has been used as best fit on lung data considered to be more reliable than urine.

In some evaluated cases very large or very small values of AMAD have been considered as best fit even if they do not represent the actual AMAD found during exposure. It can happen that if the amount absorbed to blood (as shown typically by urinary excretion) is greater at early times than predicted by the ICRP defaults in the model, IMIE can compensate by increasing deposition in the ET region. This gives rise to greater absorption and hence urinary excretion, for the same lung content. This can be done with either a very large or very small AMAD value. The estimated AMAD (and intake) in this case have nothing to do with reality. In the opinion of evaluator E2 this does improve the estimated CED but care must be put on the intake value as it is meaningless. If a software in which it is possible to change absorption parameters (like in IMBA Expert™) is available it would be better to model such an effect by increasing the rapid fraction, either explicitly or by assuming a fraction of intake is related to Type F.

Mixed AMAD
In case 43 the evaluator E4 let the AMAD vary in all the range allowed by IMIE. Based on best fit he considers 7 intakes: 1 with 3 µm AMAD, 2 with 0.01 µm AMAD and 4 with 20 µm AMAD. One particular intake of 20 µm (at 883 days) represents more than 90% of the total of 28.3 kBq intake. The other evaluator E2 considers up to 11 intakes: 6 with 0.1 µm AMAD, 3 with 20 µm AMAD, 1 with 0.001 and 1 with 0.003 µm AMAD. For 2 dates of potential intake the evaluation indicates that actually there is no intake.

Similar evaluation has been done by both evaluators for case 44.

Indications for the guidelines:
- consider the possibility to fit the different data sets to find indication about case specific AMAD. If impossible use the default 5 µm AMAD ICRP value.
- use the ratio between the cumulative faecal excretion (days 1 to 3) to lung retention on e.g. day 3 (for 241Am) as done in cases 31, 47 and 77 for evaluation of AMAD. This is based on the observation that the main effect of AMAD is to alter the ratio of deposition in the upper respiratory tract, which is mostly cleared to faeces rapidly, and deposition in the lower respiratory tract, which is mostly retained in the lungs for more than a few days.
- always consider the possibility to provide a unique value for AMAD in a case scenario: in case 11 this is not possible due to the average value of intakes estimated using different AMAD values.
- in cases of prolonged exposure and routine measurements allow for different AMAD values during the years
- give advice for exposure of several subjects in the same case scenario: though in principle AMAD can differ due to the relative position of the subjects during exposure nevertheless in the first instance the same AMAD can be assumed for more subjects.

5.6 $f_1$ values and GI tract transfer rates
In few cases (with comprehensive early monitoring data) evaluator E2 changed the parameters connected with transit in the various GI tract compartments. This was done to consider a faster clearance than that predicted by the standard ICRP models with default values.

In case 29 with IMBA evaluation an adequate fit was reached by excluding the values at day 1 and 2 and using the value at 3 h and all subsequent values (day 5 and onwards). This gave an overestimate of the whole body measurements at days 1 and 2 as the GI clearance was faster then assumed in the ICRP model. Using the increased transit rates (2.5 factor more than default) the evaluator obtained a better fit for those 2 data points. This does not change appreciably the evaluated intake and CED.
In case 47 in which there are mixed intake pathways (inhalation + wound) the main aim of evaluator E2 was to reconcile the lung and faeces data. He considered that the urinary excretion could be attributed to the wound. In reconciling lung and faeces, using the IMBA code, many attempts were tried. A detailed description of steps is made in paragraph 5.3. In this attempt also an increase of a factor 2.5 of the GI tract parameters was used. Better fit is obtained and consistency between lung and faeces was achieved. The underestimation of urine data still remained and the assumption of excretion due mainly to wound was accepted.

**Indication for the guidelines:**
- consider giving advice whether the GI tract default parameters can be changed to speed up the fecal excretion and/or whole body retention.

### 5.7 Associated radionuclides (intake of daughter radionuclide at the same time)

As indicated by the ICRP the behavior in the body of the daughter radionuclide following an intake is always considered in calculation of the dose coefficient in prospective dosimetry.

In retrospective dosimetry multiplying the intake and dose coefficient or re-evaluating the CED on the basis of the number of transformations (Us) and specific effective energy (SEE) values (as done in the IMBA code) the daughter radionuclide produced inside the body in the 50 y following the introduction is also taken into account.

If on the other hand the radionuclide is part of a couple (parent-daughter) it can be possible to introduce the daughter radionuclide as well as the parent at the time of the incident. This is the situation experienced by evaluators in some cases.

In cases related to the evaluation of $^{90}$Sr, if the radionuclide has not been purified from its daughter it is possible to find also $^{90}$Y which can introduce an increment in the total committed effective dose.

In cases 7, 26, 48 and 49 one evaluator (E7) considers the contemporary introduction of the daughter and the other (E4) does not take it into account.

In case 7 it is stated in the case description that $^{90}$Y can be considered to be in radioactive equilibrium with $^{90}$Sr at the time of intake. Also the measured urine activities are indicated as $^{90}$Sr in radiological equilibrium with $^{90}$Y.

In case 26 whole body, urine and feces data are available. Also in this case due to the fact that the source was an old powder source the committed dose due to the simultaneous intake of $^{90}$Y was added by evaluator E7.

In cases 48 and 49 mixed pathways (approx. 70% ingestion + 30% inhalation) have been evaluated. Also in this case evaluator E7 added the small increment in CED due to $^{90}$Y introduction.

In case 65 for Sr chloride which seems to show Type S behavior (instead of Type F) the contribution of $^{90}$Y has not been taken into account by evaluator E4.

In another case (No. 75) the CED due to introduction of $^{95}$Nb has been added to that of $^{95}$Zr. The increment is a little more than 31% related to the CED due to $^{95}$Zr.

**Indication for the guidelines:**
- consider to give advice on adding the CED due to simultaneous intake, in the same case scenario, of daughter radionuclides or of other radionuclides introduced in a constant ratio in respect to the main radionuclide.
- pairs of parent/daughter radionuclides to consider can be: $^{90}$Sr/$^{90}$Y, $^{95}$Zr/$^{95}$Nb, $^{99}$Mo/$^{99m}$Te, $^{103}$Ru/$^{103}$Rh, $^{106}$Ru/$^{106}$Rh, $^{132}$Te/$^{132}$I, $^{140}$Ba/$^{140}$La.
5.8 Subject related systemic retention parameters

Experience has been gained by evaluators in some subject specific parameter values. In particular two radionuclides have been involved in individual fitting of subject systemic parameters, namely $^3$H and $^{202}$Tl.

Case 6 is a controlled experiment with intake via intact skin absorption while wearing a wristwatch. It has been considered by evaluator E2 as an injection of HTO. ICRP 78 on page 38 notes that for HTO, according to the ICRP 56 model, 97% of entered activity equilibrates with body water, and is retained with $t_{1/2} = 10$ days; another 3% is incorporated in organic molecules and retained with $t_{1/2} = 40$ days. Evaluator E2 has provided a fitting with one exponential term of the increasing phase (constant rate of intake) resulting in a $t_{1/2} = 7.9$ days. A saturation curve of the type $y = \frac{a}{b}[1 – e^{-bt}]$ has been fitted to the first 29 data points. The parameters “a”, constant rate of intake, and “b” effective clearance constant have been evaluated. Evaluator E2 also notes that the “equilibrium” phase is reached earlier than expected, at ~ 18 days, less than two half-lives as expected. The intake and CED evaluated on the basis of the subject specific $t_{1/2}$ have shown values of 356 kBq and 6.5 µSv, in comparison with 315 kBq and 5.8 µSv for 10 d reference value.

In case 23, acute intake of $^3$H, the subject retention does not fit at all the reference clearance indicated in ICRP 78: 97% with $t_{1/2} = 10$ days and 3% with $t_{1/2} = 40$ days. Evaluator E2 has fitted the subject related clearance (70 data points are available up to 286 d after incident) by means of a three-exponential function with $t_{1/2} = 6.6$, 21 and 71.6 d. The default evaluation gives 4.6 GBq and 83 mSv. Using IMBA with the three exponential retention function, E2 obtained 5.7 GBq and 68 mSv. The increment in intake corresponds to a decrease in CED.

In case 63, 10 urine concentration data are available for a 150 d period for a worker who had performed tritium labelling with 4 GBq sodium borotritide. The 6 late data cannot be fitted by the ICRP 78 model so evaluator E2 to fit the clearance with a normalised retention of 99.2% with $t_{1/2} = 8.0$ d and 0.8% with $t_{1/2} = 51$ d. He supports the assumption of introduction of tritiated water. For the ICRP 78 model (evaluated with IMIE code) the estimated intake is = 317 kBq; CED = 5.8 µSv. Using IMBA (constant absolute error of 100 Bq/L) and subject specific parameters intake results = 390 kBq; CED = 5.7 µSv. The fitting resulted very well. The subject specific parameters were fitted by means of a Microsoft® Excel routine of fitting of a function with two exponential terms.

Case 64 is related to injection of $^{202}$Tl due to impurities present in normal $^{201}$Tl for cardiac perfusion. 8 data points + 2 < LOD points are available for WB retention up to 110 d after injection. The general ICRP 30 model for Tl indicates kidney 3%, $t_{1/2} = 10$ d, Rest of the body = 97%, $t_{1/2} = 10$ d. Evaluator E7 has fitted the WB data with a single exponential term resulting in a $t_{1/2} = 4.75$ d instead of 10 d clearance. With the IMIE code that performs the reference ICRP 30 model, it is not possible to fit all the data referred to the subject. A bad fit is obtained with the following values intake= 1.22 kBq CED = 0.54 µSv. Using the IMBA code and changing the clearance parameter values in both exponential terms of kidney and rest of the body = soft tissues, the values are: intake 17.2 kBq, CED = 5.7 µSv. The use of subject specific parameters determines an increase of more than one order of magnitude both in intake and CED values.

**Indication for the guidelines:**
- Consider to give advice on ways of fitting subject specific systemic parameters and on the minimum number of data needed to perform a good estimation.
Chapter 6

Special aspects

6.1 Introduction
In this chapter special topics will be addressed. These are particularly important in the evaluation of non-trivial cases mainly related to transuranics. As they appear in the description the list of items is as follows.

- Treatment of < limit of detection (LOD) data.
- Treatment of DTPA modified data
- $^{241}$Am ingrowth due to $^{241}$Pu decay
- Treatment of wounds
- Minor specific items
  o More subjects on the same case scenario
  o Same subject in 2 or more plants during monitoring period
  o Pathological effects altering the biokinetics
  o Subtracting a pre-existing contamination.

For each of them a brief description will be presented and indications for the guidelines will be given.

6.2 Treatment of < LOD data
In this paragraph the choices performed by the evaluators in cases with data less than Limit Of Detection (< LOD) will be documented.

In principle, different approaches can be assumed:
- Do not use the data points, because they are not considered to be important in the intake evaluation. This choice needs the number (proportion) of < LOD points to be small.
- Use a fraction of the value, 50% or another fraction and treat it as a “real” (> LOD) measurement.
- Use the maximum likelihood method for evaluation of intake and consider an “a priori” distribution of measured values to infer the probability of intake connected to those data points. This also can be done when many data are < LOD.

This paragraph has been divided into two parts as regarding different encountered situations: number of data < LOD relatively small, i.e. a small percentage of the data above the LOD. In contrast the second part is related to a large number of < LOD data.

In a few cases a sensitivity analysis performed by evaluator E9 permits comparison of the different choices related to the issue.

Few data < LOD

In case 30, related to $^{238}$Pu and $^{239}$Pu monitoring, evaluator E1 used the value 50% LOD with 100% uncertainty for the < LOD data. No general indication can be drawn from the evaluation as the use or not of the < LOD values. The choice on < LOD data is only one of several parameters that can affect the evaluation: time pattern of intake (continuous versus repeated acute), absorption Type etc. Evaluator E1 noted that, for $^{238}$Pu, discarding the 11 initial < LOD values, results in a very good fit of the first 5 real measurements, but this assumption may overestimate the dose.

In case 39, related to acute intake of $^{239}$Pu, there is only one < LOD data point, at 3297 days after incident. Evaluator E2 has taken for it 50% LOD with 100% uncertainty. He stated that it is already lower than other data and there are plenty of other data, so it will have little effect on the assessment. He uses the value for assessment. The same treatment of the data point was done by the other evaluator (E4).
In Case 40, related to several acute Pu intakes, one evaluator (E2) used for the two <LOD data at 4061 and 4922 days the value of 50% LOD with 100% uncertainty as done in case 39. In using the IMBA code he noted that the low data (real ones, as the <LOD data were flagged as “<LOD”) pull down the fitting. So he discarded 4 low values to reach his best estimate, which is comparable to IMIE results.

The other evaluator (E4) used for the IMIE code evaluation the standard (IMIE) assumption of replacement of <LOD data with 50% LOD with 100% uncertainty. He stated that they are already lower than most other data and there are plenty of other data, so they will have little effect. In the second part of the evaluation, performed by M. Puncher with the IMBA code, a sensitivity analysis was performed regarding the assumption adopted for <LOD data. He stated that the dataset contained 2 measurements flagged as being below LOD. Intakes were calculated by varying the treatment of these as follows: 1. <LOD flagged as “<LOD” in the fitting algorithm (IMBA assumes the most likely value of <LOD measurements based on the distribution of errors on the measurements) 2. <LOD set as equal to the LOD (set to “Real” in the fitting algorithm) or 3. <LOD measurements excluded from the fit (set to “Imaginary” in the fitting algorithm). The predicted intakes are given in Table 6.1. Despite there being only 2 <LOD measurements, the LOD value had a large impact on the predicted intake for regime 7 (large peak in the middle at 3137 d, February 1961), and therefore on the total intake.

Table 6.1: Variations on intake predictions depending on the treatment of <LOD data. Case 40.

<table>
<thead>
<tr>
<th>Treatment of &lt;LOD data in IMBA</th>
<th>Intake (kBq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flagged “&lt;LOD” (1)</td>
<td>1.47</td>
</tr>
<tr>
<td>Set = LOD “Real” (2)</td>
<td>1.81</td>
</tr>
<tr>
<td>Excluded: “Imaginary” (3)</td>
<td>1.95</td>
</tr>
</tbody>
</table>

In case 43, with several acute intakes and DTPA treatment after two potential intakes, only 12 data (out of a total of 200 data points) are <LOD: two of them in the first monitoring period and the rest between 4000 and 5500 days. Evaluator E4, for the transfer of data into IMIE, used the default assumption (50% LOD with 100% uncertainty). For the best estimate in IMIE code he excluded the data after DTPA treatment and those <LOD. He found several intakes with different AMAD and absorption Types.

The other evaluator (E2) excluded the data up to 56 d after DTPA treatment not to overestimate the related intake. For the transfer of <LOD data into IMIE he also used the default assumption (50% LOD with 100% uncertainty). In the best estimate with the IMIE code, data after DTPA are discarded but data <LOD were used. Also in this case M. Puncher made a sensitivity analysis on the assumptions related to <LOD data with the IMBA code. It turned out that using approach (1) or (2) the assumptions yield similar intakes. Ignoring the data (3) gives a slightly higher intake (see Table 6.2).

Table 6.2: Variations on intake predictions depending on the treatment of <LOD data. Case 43.

<table>
<thead>
<tr>
<th>Treatment of &lt;LOD data in IMBA</th>
<th>Intake (kBq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flagged “&lt;LOD” (1)</td>
<td>1.06</td>
</tr>
<tr>
<td>&lt;LOD set = LOD “Real” (2)</td>
<td>1.11</td>
</tr>
<tr>
<td>Excluded: “Imaginary” (3)</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Similar evaluations were done for case 44 in which there were up to 8 acute intakes and after the last one (the highest of them) 7 DTPA treatments were performed. For evaluator E4 the best estimates were obtained considering different incidents involving Type M and Type S compounds having also different AMAD values. An obvious intake, at around day 1250, was not noted as a potential incident in the case description. In making evaluations E4 used the IMIE default assumption (50% LOD with 100% uncertainty) for the transfer of <LOD data into IMIE. The best evaluation with IMIE was performed excluding the data after DTPA treatment for a period of 56 days; this was done to avoid overestimating the intake and considering as real the <LOD data. Comparing the results based on IMIE and IMBA codes on basis of dose (since different AMAD values have been used it is not useful to compare intakes) there was good agreement in several individual intakes, but
considerable difference resulted in the last, dominant one, presumably because of different error weightings (see Table 6.3).

Table 6.3: Comparison of committed effective doses between the two used codes. Case 44.

<table>
<thead>
<tr>
<th>Potential intake (day)</th>
<th>IMIE</th>
<th>AMAD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IMIE</td>
<td>IMBA</td>
</tr>
<tr>
<td>0</td>
<td>0.1</td>
<td>6.0</td>
</tr>
<tr>
<td>542</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>1250</td>
<td>1</td>
<td>9.7</td>
</tr>
<tr>
<td>3314</td>
<td>0.1</td>
<td>1.4</td>
</tr>
<tr>
<td>4090</td>
<td>0.1</td>
<td>2.7</td>
</tr>
<tr>
<td>4347</td>
<td>0.1</td>
<td>1.9</td>
</tr>
<tr>
<td>5102</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>5151</td>
<td>0.003</td>
<td>153.0</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>176.7</td>
</tr>
</tbody>
</table>

In the same evaluation, the sensitivity analysis performed by M. Puncher on the assumptions related to <LOD data with the IMBA code, as done for previous cases, indicated that using approach (1) or (2) the assumptions yield identical intakes. Ignoring the data (3) gives a higher intake (see Table 6.4).

Table 6.4: Variations on intake predictions depending on the treatment of <LOD data. Case 44.

<table>
<thead>
<tr>
<th>Treatment of &lt;LOD data in IMBA</th>
<th>Intake (kBq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flagged “&lt;LOD” (1)</td>
<td>2.3</td>
</tr>
<tr>
<td>&lt;LOD set = LOD “Real” (2)</td>
<td>2.3</td>
</tr>
<tr>
<td>Excluded “Imaginary” (3)</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Case 45 relates to a wound that occurred on the first phalanx of the right hand of a worker in a glove box in June 1981. The chemical composition of the compound handled and the isotopic ratios of the different isotopes of Pu and Am are known.

The available data are as follows (Table 6.5)

Table 6.5: Data available. Case 45.

<table>
<thead>
<tr>
<th>Data</th>
<th>No. of positive results (above LOD)</th>
<th>No. of results recorded as below the LOD</th>
<th>Total No. of results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faeces ($^{239}$Pu + $^{240}$Pu)</td>
<td>27</td>
<td>14</td>
<td>41</td>
</tr>
<tr>
<td>Faeces ($^{238}$Pu)</td>
<td>35</td>
<td>6</td>
<td>41</td>
</tr>
<tr>
<td>Urine ($^{239}$Pu + $^{240}$Pu)</td>
<td>36</td>
<td>10</td>
<td>46</td>
</tr>
<tr>
<td>Urine ($^{238}$Pu)</td>
<td>39</td>
<td>7</td>
<td>46</td>
</tr>
<tr>
<td>Urine ($^{239}$Pu + $^{240}$Pu + $^{241}$Pu)</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Evaluator E9 performed the analysis using IMBA Expert™ as reference code. He indicated that it was assumed that Pu nitrate had Type M behaviour for the absorption of plutonium from the wound to blood. In other words the retention function of plutonium in the wound was assumed to be as follows: $0.1 e^{-100t} + 0.9 e^{-0.005t}$, where $t$ is in units of days.

The <LOD data were entered as “< LOD” in IMBA Expert™ and the intake was estimated using the maximum likelihood method. Comparison was made with other assumptions related to <LOD data. (see Table 6.6)
Table 6.6: Summary of Assessments ($^{239}$Pu + $^{240}$Pu only). Case 45, reduced table.

<table>
<thead>
<tr>
<th>$^{239}$Pu Data</th>
<th>Wound characteristics</th>
<th>Comment</th>
<th>Intake (Bq)</th>
<th>Dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urine &amp; Faecal</td>
<td>Type M</td>
<td>&lt;LOD; exclude urine data on days 5 – 40 (a).</td>
<td>74</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= LOD(b); exclude urine data on days 5 – 40 (a).</td>
<td>81</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= LOD/2(b); exclude urine data on days 5 – 40 (a).</td>
<td>61</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LOD data excluded (b); exclude urine data on days 5 – 40 (a).</td>
<td>189</td>
<td>93</td>
</tr>
</tbody>
</table>

(a) Exclude data because of DTPA treatment.
(b) Treatment of LOD data was as follows: (i) “< LOD”; (ii) LOD data treated as real but equal to LOD (= LOD); (iii) treated as real but equal half the value of LOD (LOD/2); or (iv) LOD data excluded.

As indication, E9 reported: in this case, for simultaneous fitting, treating the LOD data as real and equal to the LOD value over-estimates the intake and dose by about 10% whereas setting the LOD data as real and equal to 50% LOD underestimates the intake and dose by about 18%. Excluding the LOD data overestimates the intake and dose by a factor of about 2.6.

In case 49 in which two <LOD data are present in urine excretion evaluator E7 made evaluations with IMIE using the default assumption (50% LOD with 100% uncertainty). The evaluated intake and CED are almost the same as those evaluated with IMBA Expert™ and using “Real” data = 50% LOD. In IMBA the evaluator also used the option “<LOD” (maximum likelihood). The evaluation with = 50% LOD underestimates the intake and dose by 25% in the inhalation component and by 7.5% in the ingestion component (mixed pathways evaluation) compared to the “<LOD” option. The other evaluator (E4) indicates that in IMIE the uncertainty for these 2 data <LOD is set at 100%. But using or excluding these 2 data seems not to have influence on the estimates.

In case 51 evaluator E7 indicated that due to the large number of measurements available, the use in IMBA of the 8 <LOD data for urine excretion as “<LOD” or excluding them (set to “Imaginary”) does not change the dose evaluation.

In case 64 the main problem is related to the biological half time of the subject being different from the reference value (4.75 instead of 10 d). In any case the two late <LOD data do not affect the intake and dose estimates (indication of evaluator E7).

In case 77 the 5 available urine data are all <LOD. The 8 faeces measurements are all >LOD. According to evaluator E9, for simultaneous fitting, treating the LOD urine data as “< LOD” compared with treating the data as “Real” and equal to 50% LOD only makes an 8% difference in the estimated intake and dose. For the urine data set, which is all < LOD data, if the first data value is set equal to the LOD and the rest as “< LOD” data then the estimate is only 14% different from the best estimate. Note that the first data value is set to the LOD value, as it is likely that the first value will be highest. (Table 6.7)
Table 6.7: Summary of Assessments (241Am). Case 77. (AMAD always = 5 µm).

<table>
<thead>
<tr>
<th>Data</th>
<th>Absorption Type</th>
<th>Comment(a)</th>
<th>Intake (Bq)</th>
<th>Dose mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faeces</td>
<td>S</td>
<td></td>
<td>161</td>
<td>1.39</td>
</tr>
<tr>
<td>Lung</td>
<td>S</td>
<td>= LOD</td>
<td>176</td>
<td>1.51</td>
</tr>
<tr>
<td>Urine</td>
<td>S</td>
<td>= LOD</td>
<td>&lt;115</td>
<td>&lt;0.99</td>
</tr>
<tr>
<td>Urine</td>
<td>S</td>
<td>= LOD/2</td>
<td>57</td>
<td>0.49</td>
</tr>
<tr>
<td>Simultaneous fitting to all data sets</td>
<td>S</td>
<td>&lt; LOD</td>
<td>116</td>
<td>1.00</td>
</tr>
<tr>
<td>Faeces</td>
<td>Specific</td>
<td></td>
<td>161</td>
<td>1.35</td>
</tr>
<tr>
<td>Lung</td>
<td>Specific</td>
<td></td>
<td>176</td>
<td>1.48</td>
</tr>
<tr>
<td>Urine</td>
<td>Specific</td>
<td>= LOD</td>
<td>&lt;357</td>
<td>&lt;3.01</td>
</tr>
<tr>
<td>Urine</td>
<td>Specific</td>
<td>= LOD/2</td>
<td>179</td>
<td>1.50</td>
</tr>
<tr>
<td>Urine</td>
<td>Specific</td>
<td>First data point</td>
<td>180</td>
<td>1.52</td>
</tr>
<tr>
<td>Simultaneous fitting to all data sets</td>
<td>Specific</td>
<td>&lt; LOD</td>
<td>157</td>
<td>1.32</td>
</tr>
<tr>
<td>Specific</td>
<td>Specific</td>
<td>= LOD</td>
<td>&lt; 212</td>
<td>&lt;1.79</td>
</tr>
<tr>
<td>Specific</td>
<td>Specific</td>
<td>= LOD/2</td>
<td>170</td>
<td>1.43</td>
</tr>
</tbody>
</table>

(a) Treatment of LOD data was as follows: (i) < LOD; (ii) LOD data treated as real but equal to LOD (= LOD); or (iii) treat as real but equal to half the value of LOD (LOD/2).

Large number of data < LOD

In case 5 only 7 data are > LOD, the remaining 22 measurements are all <LOD data. The values of the LOD also vary, probably because of normalization procedures and range from 1.9 to 4.8 mBq/d. The values are related to urine monitoring on an annual basis and in a brief period of time 3 to 4 urine measurements of 239Pu are performed. No further information is available other than that the worker is employed in a glove box suite handling plutonium. Monitoring data of more than 10 years are provided.

Evaluator E1 immediately had the problem to convert <LOD data to use them in the IMIE code. As a first trial the <LOD data conversion was done with default IMIE values: measurement = uncertainty associated with the measurement = 50% LOD value, and then use the data points as real measurements. The real measurements do not have given uncertainties, and so for chronic intake in manual IMIE mode the <LOD values are given the same weighting as the real measurements to determine the best fit. Evaluator E1 stated that it would be more reasonable to assign at least a constant percentage of uncertainty to real measurement values, smaller than <LOD values. This was done in a second trial, using the uncertainty curve reported in Chapter 4 of reference [27] for urine measurements. As a conservative assumption the values of the <LOD data were changed to the LOD value. Considering a chronic intake during all the period of exposure (3840 d) and letting the AMAD vary, the analysis in manual mode for chronic exposure determines a best fit for inhalation of Type S material with AMAD = 0.03 to 0.3 µm. (0.03 chosen as higher dose implied). Estimated parameters are: intake = 2.6 kBq, CED = 192 mSv. For a series of acute intakes the ICRP 78 mode of IMIE provided 3 acute intakes at days 254, 510 and 1150 for a total of 3.85 kBq and a CED = 284 mSv.

Unfortunately the evaluator E1 did not perform maximum likelihood evaluation using the IMBA code. To summarize the choice of E1:
- <LOD data points set to LOD value + 100% uncertainty and then treated as real measurements
- Estimated uncertainty of real data on basis of published study.
- Choice of chronic instead of repeated acute intake pattern.
- Best fit based on Relative Distance in IMIE code.
- No maximum likelihood evaluation performed.
Case 12 is another case with many <LOD data: 55 data are <LOD, 28 data are > LOD during 9287 d of monitoring. So two thirds of the whole data set is represented by <LOD data. In 1990 routine incorporation monitoring resulted in significant excretion rates of Pu in urine and faeces for a person working for more than 25 years in the institute. The files of the worker revealed that the person was involved in an incident in 1965 where he was burnt and heavily contaminated in the face after an explosion in a glove box. Subsequent urine analysis, however, did not show any excretion of plutonium above the detection limit of 18.5 mBq. Thus no additional investigations were performed at that time. After finding the positive results in 1990, the case had to be re-evaluated, taking into account all information available. Because of the lack of other possibilities the evaluation was made on the assumption that the positive results were due to the incident in 1965.

Three datasets are available:
- Lung data: 3 data points are available all > LOD.
- Urine data: 66 data are available. Only 3 data points are > LOD before day 1100. Then many <LOD data up to day 8923. After that time urine daily excretion data always > LOD (10 data).
- Feces data: 11 real data from day 7290 to day 9287, 1 <LOD measurement at day 8923.
- Organ data: One liver data point at day 8917 for $^{241}$Am is < 6 Bq (<LOD). Skeleton data at the same day results in 19 ±10 Bq.

Isotopic composition of the mix of Pu isotopes is provided in the case description. No $^{241}$Am is present in freshly prepared Pu.

Evaluator E9 performed the evaluation considering single data sets or simultaneous use of all data sets, the possibility to change specific absorption and also particle transport parameter values as the material was less soluble than for default Type S. Uptake via burns was also considered by E9 but he reports the experience at BNFL which suggests that generally there is not a significant uptake via burns. However, each case may be different. This case suggests there was not a significant uptake via the burn. The data of this case are consistent with an intake via the inhalation route. If there were a significant uptake via the burn then the activity in the urine, liver and skeleton would be higher compared with the predictions for inhalation alone.

For the in vivo data it was assumed that the measured $^{241}$Am activities were due to in-growth from $^{241}$Pu. This is justifiable, as the material was freshly separated plutonium. Thus, the amount of $^{239,240}$Pu can be calculated knowing the initial activity ratios of the plutonium isotopes if one assumes that $^{241}$Am behave the same as $^{241}$Pu in the body: First the activity ratio of $^{241}$Am/$^{241}$Pu was calculated as a function of time. Then the ratio of $^{241}$Pu/$^{239,240}$Pu was also calculated as a function of time. Combining these ratios and using the measured $^{241}$Am activity it is possible to estimate the activity of $^{239,240}$Pu.

For urine and faecal excretion data the values reported were assumed to be the amounts of $^{239,240}$Pu excreted in 24 h. The errors were assumed to be log normally distributed with a $\sigma_u$ of 1.8. To be conservative, the high urine excretion value on day 1108 was included in the evaluation even though the value is an order of magnitude greater than those on either side indicating that contamination of the sample may have occurred. The effect of the inclusion of this value on the ‘best estimate’ is less than 7% (Table 6.8).

The options related to the < LOD data used by E9 are as follows: (1) < LOD; (2) LOD data excluded; (3) LOD data treated as real but equal to LOD (= LOD); or (4) treated as real but equal to half the value of LOD (LOD/2).

The version of IMBA Expert™ used by evaluator E9 gives the $\chi^2$ for data above the LOD, which can be used as a measure of the goodness of fit. As a general result for the treatment of <LOD data in this case, for simultaneous fitting, excluding the LOD data or treating the LOD data as real and equal to the LOD value overestimates the intake and dose by about 26% and 56% respectively. However, setting the LOD data as real and equal to LOD/2 resulted in only a 9% overestimation in the evaluated intake compared with the best estimate.

In Table 6.8 the results reported by evaluator E9 are shown.
Table 6.8: Summary of Assessments ($^{239}$Pu + $^{240}$Pu only). Case 12.

<table>
<thead>
<tr>
<th>Data</th>
<th>Type</th>
<th>Comment (a)</th>
<th>Intake (kBq)</th>
<th>CED (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urine</td>
<td>S</td>
<td>&lt;LOD</td>
<td>11.9</td>
<td>99</td>
</tr>
<tr>
<td>Faeces</td>
<td>S</td>
<td>&lt;LOD</td>
<td>28.5</td>
<td>238</td>
</tr>
<tr>
<td>Lung</td>
<td>S</td>
<td>Used $^{241}$Am activity and activity ratios</td>
<td>78.0</td>
<td>652</td>
</tr>
<tr>
<td>Skeleton</td>
<td>S</td>
<td>=LOD ($^{241}$Am + ratios)</td>
<td>&lt;18.6</td>
<td>&lt;156</td>
</tr>
<tr>
<td>Liver</td>
<td>S</td>
<td>LOD excluded</td>
<td>23.1</td>
<td>193</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>=LOD</td>
<td>23.3</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>LOD/2</td>
<td>13.3</td>
<td>112</td>
</tr>
<tr>
<td>Urine data only</td>
<td>S</td>
<td>&lt;LOD</td>
<td>11.9</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>LOD excluded</td>
<td>23.1</td>
<td>193</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>=LOD</td>
<td>23.3</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>LOD/2</td>
<td>13.3</td>
<td>112</td>
</tr>
<tr>
<td>All the above data (simultaneous fitting)</td>
<td>S</td>
<td>&lt;LOD</td>
<td>15.7</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>LOD excluded</td>
<td>31.7</td>
<td>265</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>=LOD</td>
<td>24.6</td>
<td>206</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>LOD/2</td>
<td>14.6</td>
<td>122</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>&lt;LOD</td>
<td>2.0</td>
<td>64</td>
</tr>
<tr>
<td>Urine</td>
<td>Specific absorption parameter values</td>
<td>&lt;LOD</td>
<td>20.5</td>
<td>200</td>
</tr>
<tr>
<td>Faeces</td>
<td>Specific absorption parameter values</td>
<td>&lt;LOD</td>
<td>23.0</td>
<td>225</td>
</tr>
<tr>
<td>Lung</td>
<td>Specific absorption and particle transport parameter values</td>
<td>Used $^{241}$Am activity and activity ratios</td>
<td>53.0</td>
<td>518</td>
</tr>
<tr>
<td>Skeleton</td>
<td>Specific absorption and particle transport parameter values</td>
<td>Used $^{241}$Am activity and activity ratios</td>
<td>58.7</td>
<td>574</td>
</tr>
<tr>
<td>Liver</td>
<td>Specific absorption and particle transport parameter values</td>
<td>=LOD ($^{241}$Am + ratios)</td>
<td>&lt;32.1</td>
<td>313</td>
</tr>
<tr>
<td>Simultaneous fitting to all data sets</td>
<td>Specific absorption and particle transport parameter values</td>
<td>&lt;LOD</td>
<td>23.4</td>
<td>228</td>
</tr>
<tr>
<td>Urine</td>
<td>Specific absorption and particle transport parameter values</td>
<td>&lt;LOD</td>
<td>28.6</td>
<td>293</td>
</tr>
<tr>
<td>Faeces</td>
<td>Specific absorption and particle transport parameter values</td>
<td>&lt;LOD</td>
<td>26.1</td>
<td>268</td>
</tr>
<tr>
<td>Lung</td>
<td>Specific absorption and particle transport parameter values</td>
<td>Used $^{241}$Am activity and activity ratios</td>
<td>32.8</td>
<td>336</td>
</tr>
<tr>
<td>Skeleton</td>
<td>Specific absorption and particle transport parameter values</td>
<td>Used $^{241}$Am activity and activity ratios</td>
<td>82.4</td>
<td>845</td>
</tr>
<tr>
<td>Liver</td>
<td>Specific absorption and particle transport parameter values</td>
<td>=LOD ($^{241}$Am + ratios)</td>
<td>&lt;44.8</td>
<td>&lt;459</td>
</tr>
<tr>
<td>Simultaneous fitting to all data sets</td>
<td>Specific absorption and particle transport parameter values</td>
<td>&lt;LOD, High urine value on day 1108 ignored</td>
<td>27.4</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LOD excluded</td>
<td>36.7</td>
<td>376</td>
</tr>
<tr>
<td></td>
<td></td>
<td>=LOD</td>
<td>45.6</td>
<td>468</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LOD/2</td>
<td>31.8</td>
<td>326</td>
</tr>
</tbody>
</table>

(a) Treatment of LOD data was as follows: (i) < LOD; (ii) LOD data excluded; (iii) LOD data treated as real but equal to LOD (= LOD); or (iv) treated as real but equal half the value of LOD (LOD/2).

**Indication for the guidelines:**
- Consider the experience gained during performance of the evaluations and suggest a supported assumption related to treatment of <LOD data.
- From the majority of evaluations performed the underestimation resulting from setting the <LOD data equal to LOD/2 compared to performing a maximum likelihood estimation is small enough (order of 10%-20%) to allow including such advice in guidelines.

### 6.3 Treatment of DTPA modified data

Chelation treatment is considered by the internal dose assessor a drawback as the excretion behaviour is modified. Several problems arise in internal dose assessment in trying to deal with excretion changed by chelation therapy. In particular the excretion enhancement factor, that can be defined as the ratio of the actual excretion to the excretion expected for the same day and intake amount in absence of chelation therapy, is not known.

The second problem is the duration and the rapidity of decrease of the chelation effect. As a first approach the chelation effect can be considered as the product of an enhancement factor $E$ and a specific “decreasing effect” function $i_s(t-t_\tau)$ usually considered to be of 1 or at maximum 2 exponential terms.
One function reported in \(^{28}\) has the form of:

\[
i_c(t - \tau) = 0.6 \cdot \left( 0.95 \cdot e^{-\frac{\ln(2)(t - \tau)}{1}} + 0.05 \cdot e^{-\frac{\ln(2)(t - \tau)}{10}} \right)
\]

where \(t\) is the time after intake and \((t-\tau)\) is time after chelation.

The enhancement factor is estimate to be \(E = 77\) (values between 1 and 150 have been evaluated in specific cases).

From the point of view of the general assumptions indicated by Hall in his theory of chelation (as reported by LaBone in \(^{27}\)) there are three fundamental assumptions used in the evaluation of intakes following chelation therapy:

- At the time the chelating agent is administered, there is a quantity \(q\) of plutonium that is available, or will be available in the following 24 hours, to form a chelate. The plutonium can come from any intake that may have occurred prior to the chelation.
- The chelate is stable, i.e., it will not separate back into plutonium and the chelating agent, and will be excreted with its own excretion function \(i_c(t - \tau)\) rather than that of plutonium \(i_u(t)\).
- The biokinetics of the plutonium that was not chelated will be unaffected by the chelation except the intake will appear to be reduced from \(I\) to \(I - q\).

A chelating agent like DTPA can bind only to free monomeric plutonium in the extracellular fluids. This means that the following forms of plutonium cannot be chelated:

- intracellular plutonium,
- bulk plutonium in the lungs or a wound,
- polymeric plutonium,
- plutonium already bound by another compound.

Therefore, unless noted otherwise, LaBone in \(^{27}\) assumes that only the "free" plutonium in the bloodstream can be chelated.

The simplest approach is to exclude values that are considered to be affected by enhancement of excretion due to DTPA therapy and use only those that can be assumed to be unaffected by it at later times.

In this section the assumptions adopted by the different evaluators will be presented.

In case 14, with only two measurement values affected by DTPA treatment, evaluator E4 did not taken into account the effect of DTPA treatment on days 508 and 766 as the effect is reduced by inclusion in the average annual values (grouping of data) of the considered period. Evaluator E2 in case 14 deleted the value at 700 days because of DTPA at 508 and 766 days.

In case 15, evaluator E2 deleted the value at 700 days (he has made average of measurements between 600 and 800 days) because of DTPA at 766 days, and plenty of other data.

In case 43, Evaluator E2 assumed a 14 day half time for the DTPA effectiveness and excluded data for a period of 56 days (4 half times) for both the DTPA treatments present in the dataset. The intake estimations (considered to be the best estimate) result in lower values than those obtained if all the data are included or if they are excluded for only a 28- or 30-day period (IMIE evaluations). M. Puncher evaluating the same case 43 with IMBA excluded data for a period of approximately 60 days in accordance with 4 half times of 14 days (from 3215 to 3272 and from 4950 to 5013 days). The other evaluator (E4) did not use the data influenced by DTPA and excluded as much as in case 14 (approximately 20 data after each DTPA treatment). He said that it is considered that DTPA has an effect lasting only 24 h, but he feels that this is correct only for wounds treated with DTPA.
In case 44, in which there are up to 7 DTPA treatments after the last and largest intake, Evaluator E2 assumed a 14-d half-time for the effect of DTPA and excluded data up to 28 days after administration to avoid overestimates. However, the next measurement point is at 92 d after last DTPA treatment. Nevertheless, in this case he indicated that the last intake might be slightly overestimated (IMIE evaluation). M. Puncher in the IMBA evaluation indicates: “DTPA was administered at 5152 days (at the same time as the last putative intake) and on subsequent occasions until 5172 days. The data from day 5172 to 5264 (exclusive of latter) were excluded in the intake estimation. This time interval corresponds to approximately 60 days (possibly accounts for 4 half-lives of effect of DTPA (14 days))”. For evaluator E4 only the last data are influenced by DTPA. He tried not to use the data influenced by DTPA. He noted that it is considered that DTPA has an effect lasting only 24 h. For the best estimate, data after DTPA treatment and data <LOD were discarded.

In case 45, of pure wound intake, DTPA was used in washing the wound and was also administered by injection on days 4, 5, 8, 9, 12 and 33. Evaluator E9 presented these observations about treatment of data after DTPA: in his assessment data affected by DTPA were excluded to obtain the best estimate (excluded values between day 5 and 40 for 239+240Pu). Regarding the effect of DTPA on faecal excretion the evaluator, to be conservative, assumed that faecal excretion data were not affected by DTPA treatment. His judgement is based on the results reported in the paper of Stradling et al.[29]. They administered 238Pu as nitrate to rats by intramuscular injection and by subcutaneous injection. Thirty minutes later intraperitoneal injection of DPTA was carried out on some of the rats. The cumulative urine and faecal excretion of 235Pu on days 1 and 7 in the treated rats were compared with the untreated controls. DTPA enhanced the urine excretion by factors ranging from 25 and 91 whereas DTPA enhanced the faecal excretion only by factors ranging from 0.9 to 10. However, the increased activity in the faeces following DTPA injection could be due to contamination by the enhanced activity in the urine: the urine did fall onto the faeces. Thus, to be conservative, it was concluded that the systemic faecal excretion is unaffected by DTPA treatment because:

- The enhanced excretion factors in the urine were factors of 7 to 34 greater than that in the faeces.
- Some contamination in the faeces may have occurred.
- The amount of plutonium passing through the liver via bile is greater in rats compared with humans and therefore the effect of increased systemic faecal excretion is less in humans compared with rats.

Turning back to case 45, evaluator E9 indicated that the washing with DTPA is unlikely to have any effect as blood was gushing from the wound. DTPA was also administered by injection on days 4, 5, 8, 9, 12 and 33. Because of the effects of the DPTA two approaches were considered:

- The 239+240Pu urine data on days 5 to 40 were excluded and the 238Pu urine data on days 5 to 47 were excluded. This resulted in 74 Bq (36 mSv) for 239+240Pu and 69 Bq (31 mSv) for 238Pu.
- It was assumed that the DTPA increases urine excretion initially by a factor of 50 on day 5 and then this increase falls off with a half time of 14 days. This half-time value is based on data from Thomas LaBone. This increase was subtracted from the data. This resulted in 43 Bq (21 mSv) for 239+240Pu and 34 Bq (15 mSv) for 238Pu.

As the former approach resulted in higher estimated intakes and CED values, Evaluator E9 adopted this approach as the best approach in the final assessment.

In case 47, in which inhalation and wound intakes occurred after a glove box explosion, DTPA was administered on days 1, 2, 3, 5, 7 and 9. Treatment of data affected by DTPA was performed only on urine data. Faeces and lung data were used as given. Evaluator E9 used IMBA and excluded early urine data because of DTPA treatment. Typically the effects of DTPA fall off with a half time of about 2 weeks, and therefore he excluded one month’s urine data after the last injection of DTPA (days 1-39 excluded). For 241Am excluding data up to day 40 resulted in assessment of a much higher dose than including the early data, because it in this case there are very few 241Am in urine measurements after 40 days, and these are higher than some of the earlier measurements.

**Indication for the guidelines:**
Consider the experience gained during performance of the evaluations and suggest a supported assumption related to treatment of data affected by DTPA therapy. As general recommendations can be suggested:
Only urine data are affected, not lung, feces or organs data.
- The majority of evaluators consider to discard urine data that can be considered to be affected by DTPA treatment. In some cases up to 60 days after the DTPA treatment data were discarded on the basis of a 14 days half time of effectiveness of the treatment, for both $^{241}$Am and $^{239}$Pu.
- Other indication by La Bone [28] indicates a two exponential function with 95% decrease with half-time 1 day and 5% decrease with half time 10 days. The enhancement factor varies between 50 and 77.

6.4 $^{241}$Am ingrowth in vivo due to $^{241}$Pu decay
Limited experience has been gained on modelling ingrowth of $^{241}$Am from $^{241}$Pu at late times after intake. Only a few cases involve the problem.

In case 12 many urine data $<$LOD for $^{239+240}$Pu are available; the feces values for $^{239+240}$Pu and lung for $^{241}$Am are $>$LOD and liver and skeleton measurements for $^{241}$Am, due to an old incident (more than 25 year ago); the isotopic ratio for $^{239}$Pu and $^{240}$Pu (76%/24%) is known as well as the ratio $^{241}$Pu/$^{239+240}$Pu = 9.7. In this case evaluator E9 described estimation of $^{239+240}$Pu from the $^{241}$Am data. The steps for the evaluation, as no initial $^{241}$Am is present, are indicated as follows. The in vivo data were given as activity of $^{241}$Am. It was assumed that the measured $^{241}$Am activities were due to in-growth from $^{241}$Pu. This is justifiable, as the initial material was freshly separated plutonium. Thus, the amount of $^{239+240}$Pu can be calculated knowing the initial activity ratios of the plutonium isotopes and assuming that $^{241}$Am behaves the same as $^{241}$Pu in the body. First the activity ratio of $^{241}$Am/$^{241}$Pu was calculated as a function of time. Then the ratio of $^{241}$Pu/$^{239+240}$Pu was also calculated as a function of time. Combining these ratios and using the measured $^{241}$Am activity it is possible to estimate the activity of $^{239+240}$Pu.

In case 14 measurements of $^{241}$Am in urine at later times (8403-9009 days post intake) are available and measurements of $^{241}$Am and $^{241}$Pu at 8502 days post-intake are also reported. Evaluator E2, not knowing the initial amount of $^{241}$Am, divided the $^{241}$Am results by 2, on the basis that he supposed 50% was due to ingrowth, and the rest to $^{241}$Am initial intake. (After this evaluation was made the case description inside the IDEAS Internal Contamination Database was changed to include the isotopic composition, including a statement that $^{241}$Am was not present in the initial intake.) For $^{241}$Pu, concentrations in the 3 teeth (one below LOD) are available. Ratios of initial (decay-corrected) $^{241}$Pu to $^{239}$Pu activities are 42, 32 and $<$30. Take initial activity = 30* $^{239}$Pu activity. For $^{241}$Am, need to consider whether entirely due to ingrowth from $^{241}$Pu. Can do this in the two teeth with $^{241}$Pu above the MDA, if assume that Am formed in the body behaves the same as Pu. Consider at $t = 0$, there are N atoms of $^{241}$Pu, with decay constant p. Then activity = p N. After time t, N e$^{-pt}$ atoms of $^{241}$Pu remain. Activity = p N e$^{-pt}$. In the same time N (1-e$^{-pt}$) atoms of $^{241}$Am have formed (neglect loss through decay) with decay constant a. Activity of $^{241}$Am is then a N (1-e$^{-pt}$). Activity of $^{241}$Am/ Activity of $^{241}$Pu = a N (1-e$^{-pt}$)/p N e$^{-pt}$ = a (1-e$^{-pt}$)/p e$^{-pt}$. In the two teeth with $^{241}$Pu activity above the LOD, it was thus estimated that ingrowth accounts for about 50% of the $^{241}$Am. However, given the uncertainties, could quite possibly be all of it. (Later it was indicated in the case description that $^{241}$Am is not present in initial intake.)

In case 31 evaluators E2 and E9 give these descriptions. At $t=0$ (time of intake), $^{241}$Am activity = $A_0$. Then, due to isotopic ratio, $^{241}$Pu activity = $75 A_0$. Suppose that at $t = 0$, there are N atoms of $^{241}$Pu, with decay constant p. Then activity = p N = 75 $A_0$. After time t, N e$^{-pt}$ atoms of $^{241}$Pu remain. Therefore N (1-e$^{-pt}$) atoms of $^{241}$Am have formed (neglect loss through decay) with decay constant a. Activity of $^{241}$Am due to ingrowth from $^{241}$Pu is then $A_p(t) = a N (1-e^{-pt}) = a 75 (A_0/p)(1-e^{-pt})$ Total activity of $^{241}$Am, $A(t) = A_0 + A_p(t) = A_0 [1 + a 75 (1-e^{-pt})/p] A_0 = A(t)/[1 + (a/p) 75 (1-e^{-pt})]$. Hence, assuming Am and Pu have same biokinetic behaviour, if $^{241}$Am activity in sample at time t is $A'$, activity due to $^{241}$Am intake $A_A = A'/(1 + (a/p) 75 (1-e^{-pt}))$. 

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Indication for the guidelines:
Consider the experience gained during performance of the evaluations and suggest a model such as those presented in this section to treat $^{241}$Am due to ingrowth in body from $^{241}$Pu.

6.5 Treatment of monitoring data after wounds
From the point of view of the biokinetic behaviour, a wound can be considered as a prolonged injection with some delay between the “intake” and the entry into the bloodstream. Limited experience has been gained in this issue during the performance of evaluations. The two evaluators involved used the absorption pattern following inhalation to model the delayed intake into the bloodstream.

In case 45, it was assumed by evaluator E9 that Pu nitrate had Type M behaviour for the absorption of plutonium from the wound to blood. In other words the retention function of plutonium in the wound was assumed to be as follows: $0.1 e^{-100t} + 0.9 e^{-0.005t}$, where $t$ is in units of days. As this is questionable the evaluator himself has some doubts related to his choice. In fact he indicates also: “Should the absorption characteristics of the material in the wound be assumed to be the same as that recommended for the absorption of the material from lung to blood when no other information is given?”

In case 47 with explosion of a glove box and inhalation and wound as pathways of intake evaluator E2 considered that the urine contamination came from the continuous rate of absorption of material from the subcutaneous tissues of the wound. Since the dose estimate based on urine is much higher than if based on lung (Type S), and material is high-fired PuO$_2$, most of urine could be from wound. Evaluator E2 set the chronic intake, at a rate of 0.0001 / d (as the slow dissolution rate $s_o$ for Type S compounds) lasting for 50 y. Since he was not able to combine acute inhalation with chronic wound in IMIE, he assumed for simplicity that all urine derived from wound.

Indication for the guidelines:
Consider the experience gained during performance of the evaluations and suggest a typical rate of intake from wound.

- Both evaluators in the cases studied here used the rate of absorption from lung to bloodstream as the rate of introduction from the subcutaneous tissues to blood in case of absence on indication. In those cases they have used the rates of absorption related to the Type M and Type S absorption from lung.

6.6 Minor specific items
In this paragraph some minor items will be specified as they have been encountered during evaluation of cases.

6.6.1 More subjects on the same case scenario (same absorption type, different AMAD)
Some of the evaluated cases relate to acute inhalation of $^{60}$Co and can be used to consider the several options in performing the evaluation. These cases are Nos. 18, 19, 20, 21 and 25 in the database. Evaluators E5 and E6 found for them different AMAD values but substantially the same absorption Type (M). For case 18 evaluator E5 found AMAD=0.01 µm, in cases 19, 20, 25 AMAD=1 µm, and in case 21 AMAD=0.0003 µm.
Evaluator E6 indicated that in cases 19, 20 and 25 he assumed AMAD=1 µm, and this gave quite a good fit so he accepted this value also for case 18. In case 21 evaluator E6 indicates Type M with 5 µm AMAD and neglected the small fraction having smaller diameter and type S as indicated by the fit (see below). So his opinion is that in the first instance the same AMAD can be assumed for different subjects during the same exposure unless fitting will lead to other realistic evaluation.

Regarding the type only, evaluator E5 evaluated (as best fit) pure Type M for cases 19 and 20: a mixture of 80% M + 20% S for cases 21 and 25, and a mixture of 95% M + 5% S in case 18. Evaluator E6 also attempted in case 21 some mixture of absorption types with best fit for the mixture 75% (5 µm, M) + 25% (0.003 µm, S), but
values were not provided for the results of analyses of the other cases involved in the same event; for him it seemed to be a more realistic judgment to accept the 5 µm AMAD, Type M result.

Indication for the guidelines:
Consider the experience gained during performance of the evaluations to suggest consistent treatment of different persons in the same case scenario.
- In principle, AMAD can differ due to the relative positions of the subjects during exposure; nevertheless in the first instance the same AMAD can be assumed for more subjects.
- Absorption Type can hardly change from one subject to another and the information gained on each subject (as fitted Type) can help in adopting uniform absorption parameters for all subjects (even if not referred to ICRP default absorption Type F or M or S).

6.6.2 Exposure of the same subject in 2 or more plants during time
In case 30 (studied by Evaluator E1) the same subject was exposed to different radionuclides in different facilities. Long term measurements for alpha emitters do not distinguish between the exposure situations and so urine measurements are related to a mixture of intakes due also to different radionuclides (in this case 238Pu and 239Pu).

Indication for the guidelines:
Consider the experience gained during performance of the evaluations to suggest unified approach in case of exposure of the same subject in more working places.

6.6.3 Pathological effects altering the biokinetics
In case 58 there was possible damage to lungs and kidneys due to huge intake of uranium. Urinary excretion of U increases to a peak at about 60 days after incident and returns to background level at about 1060 days. This was considered by changing the HRTM absorption parameters, without using the bound state, since evidence suggests no significant “binding” of uranium, and gut absorption (f1 value reduced to reduce early excretion). In this case it is difficult to reproduce sharp enough peak with the model. However, an adequate fit can be obtained.

Indication for the guidelines:
Consider the possibility to change absorption parameter values also taking into account pathological state.

6.6.4 Subtracting a pre-existing contamination
In the case scenario of case 91 it is stated that “Fish (1960) (the author of the original paper) noted that subject probably had many low-grade exposures over a period of several years and estimated that 244 µg HEU (18.1 Bq) was due to existing, effectively permanent chest activity (lymph nodes).” So pre-existing contamination was subtracted from the data by evaluator E2.

Indication for the guidelines:
Consider the possibility to eliminate pre-existing contamination if known.
Chapter 7

Interpretation level: steps in evaluation

7.1 Introduction
In this chapter the information related to the use of default instead of case specific evaluation for cases in which the estimated value is less than the interpretation level will be presented. The interpretation level has been set equal to the value of 1 mSv. This was agreed during the Bologna Contractors Meeting and it is considered to be that level above which a best fit evaluation can be considered of sufficient interest to be performed.

In the present chapter the adequacy of the “reference” procedure for intakes that determine values of CED less than 1 mSv will be discussed. This forms the basis from the gained experience to provide guidance for the cases in which small values of CED are involved.

7.2 Considerations related to the possibilities of using default parameters instead of best-estimation parameters for doses below the interpretation level.
The selection of cases was performed on the basis of evaluated cases in the database. In Table 7.1 the evaluated values are reported. The best-estimated value is that reported by the evaluator without considering the fact that for low doses some simplified mode of assessment can be advised. The reference value reported there, conversely, has been chosen on the basis of the case taking CED values derived from the default parameters as indicated by ICRP publications, e.g. in case of $^{60}$Co cases 18, 19, 20, 21, 25, and 92 a 5 µm AMAD and absorption Type M have been chosen. In other cases the reference CED values have been evaluated using default ICRP parameters, also adopting in some cases one of the estimated CED and considering it as a reference value. Usually the reference evaluations are performed in an easier way than the best fit evaluations.

Table 7.1: Values of best-estimated and reference values for committed effective dose evaluations of cases with CED value less than interpretation level (1 mSv)

<table>
<thead>
<tr>
<th>Radio isotope</th>
<th>Case</th>
<th>Evaluator</th>
<th>Best-estimated CED (mSv)</th>
<th>Reference CED (mSv)</th>
<th>Ratio = reference / best-estimated CED values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{60}$Co</td>
<td>18</td>
<td>E6</td>
<td>0.356</td>
<td>0.278</td>
<td>0.781</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>18</td>
<td>E5</td>
<td>0.47</td>
<td>0.278</td>
<td>0.591</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>19</td>
<td>E6</td>
<td>0.219</td>
<td>0.142</td>
<td>0.648</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>19</td>
<td>E5</td>
<td>0.26</td>
<td>0.142</td>
<td>0.546</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>20</td>
<td>E6</td>
<td>0.174</td>
<td>0.124</td>
<td>0.713</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>20</td>
<td>E5</td>
<td>0.186</td>
<td>0.124</td>
<td>0.667</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>21</td>
<td>E6</td>
<td>0.108</td>
<td>0.114</td>
<td>1.056</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>21</td>
<td>E5</td>
<td>0.137</td>
<td>0.114</td>
<td>0.832</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>25</td>
<td>E5</td>
<td>0.11</td>
<td>0.044</td>
<td>0.400</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>25</td>
<td>E6</td>
<td>0.094</td>
<td>0.044</td>
<td>0.468</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>92</td>
<td>E5</td>
<td>0.0944</td>
<td>0.094</td>
<td>0.996</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>92</td>
<td>E6</td>
<td>0.132</td>
<td>0.094</td>
<td>0.712</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>1</td>
<td>E7</td>
<td>0.73</td>
<td>0.76</td>
<td>1.041</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>9</td>
<td>E1</td>
<td>0.188</td>
<td>0.182</td>
<td>0.968</td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>9</td>
<td>E6</td>
<td>0.19</td>
<td>0.189</td>
<td>0.995</td>
</tr>
<tr>
<td>$^3$H</td>
<td>6</td>
<td>E3</td>
<td>0.0058</td>
<td>0.0058</td>
<td>1.000</td>
</tr>
<tr>
<td>$^3$H</td>
<td>6</td>
<td>E4</td>
<td>0.00577</td>
<td>0.0058</td>
<td>1.005</td>
</tr>
</tbody>
</table>
The data are 34 values, 13 values are greater than or equal to 1, and 21 values are less than 1. The average value of all data is 0.89.

The same data are reported in Figure 7.1. As abscissa the reference values have been taken and for ordinate the ratio between reference CED and best estimate CED has been plotted (last column in Table 7.1). A value of ratio less than 1 indicates an underestimation when using the reference value instead the best-estimated value. A value greater than 1 means an overestimation of the CED when using the reference value.

In Figure 7.1 the two curves for the ratio CED-reference/CED-Best-estimation have been also reported

\[
Upper \_ \text{limit} = 3 - \left(\frac{\log_{10} CED + 3}{2}\right)
\]

\[
Lower \_ \text{limit} = \frac{1}{3 - \left(\frac{\log_{10} CED + 3}{2}\right)}
\]

with CED expressed in mSv. These curves are descending (Upper limit) or ascending (Lower limit) in linear shape on a logarithmic paper.

The equations of these curves have been developed taking into account that the ratio between the reference CED and best-estimate CED, when approaching the value of 1 mSv, can be underestimated or overestimated in a similar way to that present in external dosimetry (range equal 1/1.5 – 1.5).

When approaching the lower value of 0.001 mSv, the under- or over-estimation can be allowed to be twice as much i.e. up to a factor of 3 (range 1/3 – 3).

A selection in relation to the CED reference value has been done.

In the range 0.001 to 0.01 mSv there are a few data related to $^3$H (the values of the ratio are around 1) and to $^{202}$Tl for which ratio is less than 1.5.

In the range 0.01 to 0.1 mSv most of the $^{60}$Co data are present. As can be seen in the figure, using reference instead of best-estimation values gives underestimates that only in two cases are greater than allowed by the limiting curve but are near it.

In the range 0.1 to 1 mSv no problems of undue underestimation, as all the values are inside the limiting curves.
From the experience gained from the evaluation of cases in general there is an underestimation in using reference values instead of best estimate CED values. This underestimation generally is not greater than that allowed for external dosimetry. In only two evaluations out of 34 and only in the range 0.01 to 0.1 mSv the ratio CED-reference / CED-Best-estimate values is slightly outside the limiting curves based on the assumptions of comparative uncertainties in internal and external dosimetry.

**Indication for the guidelines.**
- Suggest the adoption of the limiting curves related to overestimation or underestimation for values of CED less than the interpretation level and base the choice on comparison with external dosimetry.
- Indicate that the use of reference values in the ranges of CED values less than 1 mSv does not introduce an underestimation that is greater than that allowed by curves.
- Suggest the use of reference methodologies if the first hand evaluation provides values less than the interpretation level of 1 mSv.
Chapter 8

Conclusions

In Work Package 3 of the IDEAS project for the development of “General guidelines for the estimation of committed dose from incorporation monitoring data” many case studies have been evaluated by the contractors. The experience gained is related to 95 independent evaluations on 52 cases, (17 radioisotopes) and the comparison of different evaluator’s approaches allows general features of evaluation of monitoring data to be derived.

The items presented in this report are related to input data, evaluating parameters and special aspects (e.g treatment of < LOD data or treatment of data after chelation therapy). Suggestions on the use of reference values instead of best-estimate values for evaluations that resulted in a committed effective dose less than an “interpretation level” (1 mSv) has also been provided.

In the process of development of guidelines the experience gained, summarized here, can be usefully adopted.

Advice relating to data

Conversion of monitoring data:

- Consider the criteria to verify the ratio of different radioisotopes in a mixture using data inside the same data set (e.g. later measurements) either on the same subject but in another type of monitoring (e.g. feces) or externally from the monitoring data sets (case description).
- Provide some reference percentages for the uranium composition at different enrichment ratios (depleted uranium, natural uranium, low enriched uranium, high enriched uranium).
- Provide some reference ratios values for Pu-Am mixtures encountered in different types of facilities.
- Make explicit indication to correct measured data for radioactive decay if not considered in monitoring values.

Uncertainties in data:

Consider the experience gained on uncertainties in monitoring data for the different monitoring types, presented in Section 4.3, and propose default values for uncertainties related to type of monitoring and amount of measured radioactivity, considering also the assumptions adopted by evaluators.

Grouping of data:

Consider the experience gained in grouping of data to provide criteria not to give undue weight to some part of the monitoring period.

Indicate proper way to calculate daily excretion rates on the basis of concentration measurements in single voids.

Outlying data:

Consider the experience gained presented in section 4.5 and give criteria to exclude data.

Early data:

Consider if the models developed for prospective dosimetry can be used in interpretation of early measurements.

Interpretation measurement data:

Use model data related to the part of the body that has effectively been measured.

Best monitoring type to evaluate intake or CED

Consider the experience gained to indicate the proper monitoring type for the dose evaluations.

- Indicate that for $^{90}$Sr feces data are less reliable than urine data (cases 1, 26 and 65).
The experience of case 47 (mixture of inhalation and wound) indicates that inhalation pathway can be better evaluated by means of lung data while continuous wound uptake can be better evaluated by means of urine data.

For relatively insoluble compounds of U, lung data should be more reliable than urine. Urine data can provide better estimation of absorption Type.

**Advice relating to parameters involved in the assessment**

**Time pattern of intake:**
Consider the experience gained during performance of the evaluations, and presented in Section 5.2, to suggest a default approach of assessment in absence of information related to time pattern of intake, especially in case of repeated routine measurements.

**Pathway of intake:**
Consider the experience gained reported in Section 5.3 especially to evaluate mixed paths of intake.

**Absorption type:**
- Consider the experience gained during performance of the evaluations to suggest a default approach in absence of information related to the compound absorption Type.
- Consider the indications on compound specific parameters such as those for U, presented in ICRP Supporting Guidance 3 [18] and in report NRPB-W22 [24].
- In the case of repeated intakes, and in the absence of specific information, give advice if identical Type for each intake or different Types can be assumed.
- Consider the experience gained during the performance of evaluations and provide advice either to follow the ICRP guidance on compound specific absorption type or that indicated by the fitting of the measured data.
- Discuss, in the guidelines, the possibility in the same case scenario of different Types of compounds for different radionuclides.

For advanced evaluation of monitoring data a 5-step approach, with increasing complexity, in fitting procedure can be proposed:
- Try to find the best fit using one out of 3 default Types (F or M or S).
- Consider a mixture of Types and evaluate the percentages of them on the basis of a goodness of fit metric.
- Change absorption parameters on the basis of in vivo experiments (as e.g. $f_r = 0.04, s_r = 1 \text{ d}^{-1}$ and $s_s = 0.001 \text{ d}^{-1}$ in case 91).
- Consider also using $f_b$ and $s_b$ for bound state if necessary, (as in case 31 for $^{241}$Am nitrate).
- Change fractions of mechanical transfer as $A_{I1}/A_I$ in case 31 or transfer rates as the rate $A_{I3} \rightarrow b_{b1}$ in case 12.

**AMAD value:**
- Consider the possibility to fit the different data sets to information about case specific AMAD. If impossible use the default 5 µm AMAD ICRP value.
- Use the ratio between the cumulative faecal excretion (days 1 to 3) to lung retention on e.g. day 3 (for $^{241}$Am) as done in cases 31, 47 and 77 for evaluation of AMAD; this is based on the observation that the main effect of AMAD is to alter the ratio of deposition in the upper respiratory tract, which is mostly cleared to faeces rapidly, and deposition in the lower respiratory tract, which is mostly retained in the lungs for more than a few days.
- Always consider the possibility to provide a unique value for AMAD in a specific case scenario (in case 11 this is not possible due to the average value of intakes estimated using different AMAD values).
- In cases of prolonged exposure and routine measurements allow for different AMAD values during the years.
- Give advice for exposure of several subjects in the same case scenario: though in principle AMAD can differ due to the relative position of the subjects during exposure nevertheless in the first instance the same AMAD can be assumed for more subjects.

**$f_1$ values and GI tract transfer rates:**
Consider giving advice on whether the GI tract default parameters can be changed to speed up the fecal excretion to better represent early fecal excretion.
Associated radionuclides:
- Consider giving advice on adding the CED (Committed Effective Dose) due to simultaneous intake of daughter radionuclides or due to other radionuclides introduced with constant ratio in respect of an indicator radionuclide in the same case scenario.
- Pairs of parent/daughter radionuclides to consider can be: $^{90}\text{Sr}/^{90}\text{Y}$, $^{95}\text{Zr}/^{95}\text{Nb}$, $^{99}\text{Mo}/^{99m}\text{Tc}$, $^{103}\text{Ru}/^{103}\text{Rh}$, $^{106}\text{Ru}/^{106}\text{Rh}$, $^{132}\text{Te}/^{132}\text{I}$, $^{140}\text{Ba}/^{140}\text{La}$.

Subject related systemic retention parameters:
Consider giving advice on fitting subject specific systemic parameters and on the minimum number of data needed to perform a good estimation.

Advice relating to special aspects of dose evaluation

Treatment of <LOD data:
- Consider the experience gained during performance of the evaluations and suggest a justified assumption related to treatment of <LOD data.
- From the majority of evaluations performed the underestimation considering the <LOD data equal to LOD/2 compared to performing a maximum likelihood estimation is small enough (order of 10%-20%) to allow giving such advice in guidelines.

Treatment of DTPA modified data:
Consider the experience gained during performance of the evaluations and suggest a justified assumption related to treatment of data affected by DTPA therapy. These recommendations can be suggested:
- Only urine data are affected by DTPA therapy, not lung, feces or organ data.
- The majority of evaluators consider to discard urine data that can be considered to be affected by DTPA treatment. In some cases up to 60 days after the DTPA treatment data were discarded on the basis of a 14 days half time of effectiveness of the treatment, for both $^{241}\text{Am}$ and $^{239}\text{Pu}$.
- Other indication by La Bone [28] indicates a two exponential function with 95% decrease with half-time 1 day and 5% decrease with half time 10 days. The enhancement factor varies between 50 and 77.

$^{241}\text{Am}$ ingrowth in vivo due to $^{241}\text{Pu}$ decay:
Consider the experience gained during performance of the evaluations and suggest a model such as those presented in Section 6.4 to treat $^{241}\text{Am}$ due to ingrowth in body from $^{241}\text{Pu}$.

Treatment of monitoring data after wounds:
Consider the experience gained during performance of the evaluations and suggest a basis for estimating rate of intake from wound.
- Both evaluators in the experienced cases have used the rate of absorption from lung to bloodstream as the rate of introduction from the subcutaneous tissues to blood in case of absence on indication. In those cases they have used the rates of absorption related to Type M and Type S absorption from lung.

More subjects in the same case scenario:
Consider the experience gained during performance of the evaluations to suggest uniform treatment of different persons in the same case scenario.
- In principle, AMAD can differ due to the relative positions of the subjects during exposure; nevertheless in the first instance the same AMAD can be assumed for more subjects.
- Absorption Type can hardly change from one subject to another and the information gained on each subject (as fitted Type) can help in adopting uniform absorption parameters for all subjects (even if not referred to ICRP default absorption Type F or M or S).

Exposure of the same subject in 2 or more plants during time:
Consider the experience gained during performance of the evaluations to suggest unified approach in case of exposure of the same subject in more working places.
Pathological effects altering the biokinetics:
Consider the possibility to change absorption parameters also taking into account pathological state.

Subtracting a pre-existing contamination:
Consider the possibility to eliminate pre-existing contamination if known.

Evaluations with CED values less than the interpretation level (1 mSv):
- Suggest the adoption of the limiting curves related to overestimation or underestimation for values of CED less than the interpretation level and justify the choice in comparison to external dosimetry
- Indicate that the use of reference values in the ranges of CED values less than 1 mSv does not usually introduce an underestimation that is greater than that allowed by curves.
- Suggest the use of reference methodologies if the first hand evaluation provides values less than the interpretation level of 1 mSv.

These suggestions form the basis for the general guidelines to be developed in IDEAS Work Package 4.

Attention must also be taken in other issues as indicated in a recent paper, related to a UK intercomparison on internal dosimetry \[^30^\]. In some cases the lack of information (few data) led to differing interpretations of the intake scenario and subsequently large variation in the assessed intakes and doses, especially in cases of wound and possible inhalation (see case 1 in paper \[^29^\]). In other cases when there is a reasonable quantity of monitoring data available it is the different judgments on the most appropriate type of data to use to estimate intake that determines the spread of assessed intake values (case 6 in paper \[^29^\]). Another issue, also seen in the present report, is allowing for the effect of DTPA treatment on biokinetics of the radionuclide. If no attempt has been made to correct the assessed dose for the effect of DTPA, large overestimation can occur. The effect of DTPA on the different types of monitoring data must also be considered: while a large effect on urine excretion has been considered, only small effects on faeces or on lung data have been assumed (case 5 in paper \[^29^\]). A final remark is also given on the criteria to change the ICRP default values for parameters. The question that arises from case 4 in paper \[^29^\], is when should parameters, such as AMAD or absorption type (as in case 65 for \(^{90}\)Sr chloride), be altered from recommended default values and on what judgment are such changes based? In the practical case if the only data available are from excretion analysis should the recommended ICRP default values for parameters, or values derived from modelling the individual case, be used when assessing intake and dose? How many data are necessary to fit individual parameters?

Care must be taken to answer these questions and provide advice and guidelines to harmonize the way of performing internal dose assessment.
Annex 1: List of evaluators, affiliation and code used throughout the document

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eric Blanchardon</td>
<td>IRSN</td>
<td>E1</td>
</tr>
<tr>
<td>Michael Bailey (and/or Matthew Puncher)</td>
<td>NRPB</td>
<td>E2</td>
</tr>
<tr>
<td>Bernard Le Guen</td>
<td>EDF</td>
<td>E3</td>
</tr>
<tr>
<td>Christian Hurtgen</td>
<td>SCK•CEN</td>
<td>E4</td>
</tr>
<tr>
<td>Vladimir Berkovski</td>
<td>RPI</td>
<td>E5</td>
</tr>
<tr>
<td>Andor Andrasii</td>
<td>KFKI</td>
<td>E6</td>
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<td>Carlo-Maria Castellani</td>
<td>ENEA</td>
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<td>Hans Doerfel</td>
<td>FzK</td>
<td>E8</td>
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<tr>
<td>James Marsh</td>
<td>NRPB</td>
<td>E9</td>
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</table>
REFERENCES
10 ICRP Publication 68 Dose Coefficients for Intakes of Radionuclides by workers Replacement of ICRP Publication 61 Annals of the ICRP Vol. 24, No. 4, 1995
19 See reference 6

25 See reference 18

26 See reference 6

27 See reference 16.

