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Third European Intercomparison Exercise on Internal Dose Assessment

Results of a Research Programme in the Framework of the EULEP/EURADOS Action Group "Derivation of Parameter Values for Application to the New Model of the Human Respiratory Tract for Occupational Exposure"

1997-1999

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Abstract

The EULEP/EURADOS Action Group „Derivation of Parameter Values for Application to the New Model of the Human Respiratory Tract for Occupational Exposure“ has initiated a new intercomparison exercise on internal dose assessment. During the last few years the ICRP has developed a new generation of more realistic internal dosimetry models, including the Human Respiratory Tract Model (ICRP Publication 66) and recycling systemic models for actinides. These models have been used to calculate dose coefficients, which have been adopted in the revised EURATOM Directive.

This recent intercomparison exercise 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. It also took into account some aspects which have not been considered in previous exercises, such as air monitoring, natural radionuclides, exposure of the public, artificially created cases and artificially reduced information. Seven case scenarios were distributed, dealing with H-3, Sr-90, I-125, Cs-137, Po-210, U-238 and Pu-239, and covering different intake scenarios and all monitoring techniques. Results were received from 50 participants, 43 representing 18 European countries and 7 from five countries outside Europe. So it is by far the largest exercise of this type carried out to date. Most participants attempted more than half of the cases. Thus on average there were 35 responses per case with a total of about 240 answers, giving a good overview of the state of the art of internal dosimetry. The results in terms of intake and committed effective dose were log-normally distributed with the geometric standard deviation ranging from about 1.2 for the cases dealing with H-3 and Cs-137, up to about 2.4 for the cases dealing with Pu-239.

A key feature of the exercise was a Workshop, involving most of the participants, at which each case and the various approaches taken to assessing it were discussed. Several reasons for the differences in the results were identified, including different assumptions about the pattern of intake, and the choice of model. An important conclusion of the exercise was the need to develop agreed guidelines for internal dose evaluation procedures to promote harmonisation of assessments between organisations and countries.

Dritter Europäischer Vergleich zur internen Dosimetrie

Ergebnisse eines Forschungsprogramms im Rahmen der EULEP/EURADOS Aktionsgruppe "Derivation of Parameter Values for Application to the New Model of the Human Respiratory Tract for Occupational Exposure"
1997-1999

Zusammenfassung

Die EULEP/EURADOS Arbeitsgruppe „Derivation of Parameter Values for Application to the New Model of the Human Respiratory Tract for Occupational Exposure“ hat einen neuen Vergleich zur internen Dosimetrie initiiert. Hintergrund des neuen Vergleichs ist die Tatsache, daß die ICRP in den letzten Jahren eine neue Generation von biokinetischen Modellen entwickelt hat, die eine realistischere Beschreibung der internen Dosimetrie ermöglichen als die früheren Modelle. So wurde unter anderem ein neues Modell für den Atemtrakt entwickelt (ICRP Publikation 66) sowie verschiedene neue systemische Modelle für die Aktiniden, bei denen erstmalig auch Rezirkulationsvorgänge berücksichtigt werden. Mit diesen neuen Modellen wurden neue Dosisfaktoren berechnet, die in die neuen EURATOM Grundnormen aufgenommen worden sind.

Der neue Vergleich bezog sich speziell auf die Auswirkungen der neuen Modelle und der neuen Modellparameter auf die Berechnung der internen Dosis aus den Inkororporationsmeßdaten. Außerdem wurden in den neuen Vergleich auch einige Aspekte aufgenommen, die bei früheren Vergleichen nicht berücksichtigt worden sind, wie z. B. die Raumluftüberwachung, die natürliche Radioaktivität, die innere Strahlenexposition der Bevölkerung, theoretisch konstruierte Fälle sowie Fälle mit künstlich reduzierter Information. Es wurden sieben Fallstudien verteilt, die sich mit Inkorporationen von H-3, Sr-90, I-125, Cs-137, Po-210, U-238 und Pu-239 befaßten und die verschiedene Zufuhrszenarien sowie alle gängigen Überwachungsverfahren abdeckten. Die Fallstudien wurden von 43 Teilnehmern aus 18 europäischen Ländern und von 7 Teilnehmern aus 5 weiteren Ländern bearbeitet. Die meisten Teilnehmer lieferten Abschätzungen für mehr als die Hälfte der Fallstudien. So lagen für jeden Fall durchschnittlich 35 Abschätzungen vor, die einen guten Überblick über den gegenwärtigen Stand der internen Dosimetrie gaben. Die Ergebnisse für die Aktivitätszufuhr und die effektive Folgeäquivalentdosis können durch logarithmische Normalverteilungen beschrieben werden, wobei die geometrische Standardabweichung zwischen etwa 1,2 bei den H-3- und Cs-137-Fällen und etwa 2,4 bei den Pu-239-Fällen liegt.

Eine Schlüsselfunktion des Vergleichs kam einem Workshop zu, bei dem die Fallstudien und die verschiedenen Lösungsansätze mit nahezu allen Teilnehmern diskutiert werden konnten. So konnten einige Ursachen für die Abweichungen der Ergebnisse identifiziert werden, wie z.B. unterschiedliche Annahmen hinsichtlich der Zufuhrmuster sowie der verwendeten Modelle. Es wurde ein dringender Bedarf zur Entwicklung allgemeiner Richtlinien für die Auswertung von Inkorporationsmeßdaten in Hinblick auf eine Harmonisierung der Dosisabschätzungen in den verschiedenen Institutionen festgestellt.

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Foreword

Background

The Third European Intercomparison Exercise on Internal Dose Assessment has been carried out within the framework of a joint Action Group of EULEP (European Late Effects Project Group) and EURADOS (European Radiation Dosimetry Group). As part of the Nuclear Fission Safety Programme of the Fourth Framework Programme of the European Commission, a Joint Concerted Action has been carried out (under contract N° FI4P-CT96-0061) during the period 1997-1999 between three organisations involved in promoting collaboration and co-operation between European institutes in the field of radiation protection: EULEP, EURADOS and UIR (International Union of Radioecologists). The Concerted Action itself consists of a number of Action Groups involving members of one or more of the organisations. The activities carried out under the Concerted Action have been reported in a joint Newsletter produced as one of the joint actions between all three organisations, at approximately 6-month intervals. (Limited numbers of copies of the Newsletter are available on request from its Editor, Dr Pascal Pihet, IPSN, BP N° 6, F-92265 Fontenay-aux-Roses Cedex, France.).

The EULEP-EURADOS Action Group (1.3) entitled "Derivation of parameter values for application to the new model of the human respiratory tract for occupational exposure", had the overall objective of undertaking a review of the behaviour of inhaled radionuclides in chemical forms currently encountered in facilities in the European Union (EU). Inhalation is the main route of intake of radionuclides by workers. The rates at which radionuclides deposited in the lungs are absorbed into blood (absorption rates) depend upon the physico-chemical form of the inhaled material. Absorption rates thus determine retention in, and doses to, the respiratory tract, amounts deposited in other organs, and excretion rates.

The ICRP Publication 66 Human Respiratory Tract Model for Radiological Protection (HRTM) provides default parameter values for use where more specific information is not available, according to whether absorption is considered to be fast, moderate or slow (Type F, M, or S respectively). These defaults have been used to calculate general-purpose dose coefficients (doses per unit intake) for workers and the public (ICRP Publications 68, 71, and 72). In ICRP Publications 68 it is recommended, as an interim measure, that where a compound was assigned to inhalation Class D, W or Y in Publication 30, it should be assigned to HRTM Type F, M or S respectively. It is recognised, however, that the Publication 30 classification of compounds is largely based on reviews conducted 20 – 30 years ago.

ICRP also recommends that specific information should be used in preference to defaults whenever appropriate, and the HRTM was designed to use such information. It is likely to be important to use material-specific absorption rates in situations where individual monitoring and internal dose assessments are carried out, because their use implies that there exists a potential for significant intakes. Furthermore, lung retention and urinary excretion, which are often used to monitor exposure, can be very sensitive to absorption rates.

There is therefore a need for absorption parameters for use with the HRTM to be derived for important compounds used in facilities in the European Union (EU), and in other cases for compounds to be assigned to the default Types according to the best current information. Over the next several years the Task Group on Internal Dosimetry of ICRP Committee 2 will review the classification of inhaled compounds of radionuclides, and produce full revisions of ICRP Publications 30 and 54. The work in this Action Group will be important in ensuring that practical problems in radiation protection in the member states are properly represented.

Tasks of the Action Group

The work of the Action Group formed three main Tasks:

- To collate and analyse information from the literature on experimental studies relating to the biokinetics following inhalation of compounds of radionuclides of importance for occupational exposure (EULEP). The EULEP members thus needed experience of conducting such experiments or of deriving such information from their results.

- To collate two forms of information: (i) important chemical forms of radionuclides encountered or likely to occur in workplaces in EU member states. (ii) Measurements following inadvertent intakes that provide information about the biokinetics of inhaled radionuclides, or that can be used to check model predictions based on animal experimental data, or might provide examples for future exercises (EURADOS). The members of EURADOS therefore needed to represent a number of member states and either be involved in, or have contacts with occupational internal dosimetry services.

- To conduct an inter-laboratory comparison exercise on the assessment of intakes and doses from monitoring datasets (EURADOS). This intercomparison exercise forms the subject of this report. Although the exercise was not concerned directly with the overall objective of the Action Group, there were several reasons for including it. Two such exercises had previously been conducted successfully by EURADOS. Their value, and the need for another exercise during the time-scale of this programme, was recognised. The expertise and background needed to conduct such an exercise was similar to that needed for collating the information on workplace exposure. Furthermore, the implementation of the HRTM by internal dosimetrists was a topical issue for consideration in an exercise, since it was applied in the recent EURATOM Directive.

Membership of the Action Group

Co-Chairman	Michael Bailey	NRPB, UK;
	Hans Doerfel*	FZK, Germany
EULEP	Eric Ansoborlo	IPSN, France
	Asuncion Espinosa	CIEMAT, Spain
	Wolfgang Kreyling	GSF, Germany
	Jean-Luc Poncy	CEA, France
	Neil Stradling	NRPB, UK
EURADOS	Andor Andrasi*	AERI, Hungary
	Alan Birchall	NRPB, UK
	Klaus Ennow	NIRH, Denmark
	Carlo-Maria Castellani*	ENEA, Italy
	Christiane Chevalier	EDF, France
	Christian Hurtgen	CEN-SCK, Belgium
	Lennart Johansson	U of UmeΔ, Sweden
	Bernard LeGuen	IPSN & EDF, France
	Maria Lopez Ponte	CIEMAT, Spain
	Giuseppe Tarroni*	ENEA, Italy

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Complementary databases on radioactive materials

The Action Group considered that the compilation of databases would facilitate both tasks, and that such databases might well become useful resources after the end of this programme. They were built by Christian Hurtgen and Michael Bailey, respectively, both using Microsoft Access, because it was widely available amongst the members.

EURADOS Database on Internal Radiation Exposure of Workers

One aim was to collate information on the chemical forms of radionuclides to which workers are exposed, the extent of the exposures, and methods used to monitor them. The other aim was to identify existing well-documented cases of internal contamination, which might be used for comparison with model predictions, or in future inter-comparison exercises. A questionnaire was first developed by the Group as a simple mechanism to obtain the information from relevant organisations. Each member was assigned one or more countries in which to circulate it and from the responses compiled a database for each country.

For each entry in the database, the following information has been gathered:

- element: symbol of the element;
- isotope: mass number of the element;
- physical form: aerosol, gas, solid, powder or solution;
- chemical form: chemical compounds;
- AMAD µm: particle size distribution of the aerosol or powder;
- number of workers: number of workers potentially exposed to the radioisotope;
- activity in Bq/year: order of magnitude of the activity handled per year in the laboratory;
- number monitored: number of monitored workers;
- monitoring frequency: monitoring interval in days;
- monitoring type: whole-body, lung, thyroid, urine analysis, faeces analysis, air concentration monitoring, dosimeter;
- documented case: identification of cases of internal contamination which have been followed during a specified period of time by one or more methods of monitoring;
- remarks: any complementary information on the data given above;
- firm_ID: identification code for the organisation where the radioisotope is handled. Another table contains information describing the type of activity in which this organisation is involved. The complete information on the organisation is kept by the Action Group member responsible for the database in each country;
- industry type: area in which the organisation is involved; *nuclear* such as mining, milling, fuel fabrication, fuel reprocessing, decommissioning, reactor operation, research and waste management and disposal; or *non-nuclear* such as industrial research, medical therapy or imaging, medical research, medical teaching, radio-pharmaceutical, and waste management and disposal.

By the time of the Workshop in May 1999, over 500 records had been entered from about 120 organisations (about 50 of them nuclear industry) in 14 countries.

Database on Experimental Studies of Lung Clearance

EULEP members of the Group have been compiling the database on inhalation experiments. Its structure was finalised in May 1998, and since then data have been entered. The aim is to summarise information on experiments which could provide material-specific values of the parameters which define the rate of absorption of radionuclides from the lungs to the blood for use with the HRTM. The database has two main tables: *References* and *Inhalation Experiments*.

The *References* table contains information about each publication reporting relevant experiments:

- Citation details: authors; title; publication; volume; pages; date.
- Comment: e.g., whether it contains the original data; an analysis of HRTM parameter values; a review giving only a summary.
- Abstract.

The *Inhalation Experiments* table summarises information on each experiment giving information about dissolution in the respiratory tract and absorption to blood. Although called *Inhalation*, it includes experiments in which the material was injected into the lungs, and *in vitro* experiments designed to assess dissolution in the lungs.

The first section contains details on the material:

- Element; isotopes; chemical form; source (e.g., name of facility, laboratory).
- Characteristics of size distribution: median; geometric standard deviation.
- Density; specific surface area.
- Comment on material (e.g., method of preparation).

The second section contains details of the experimental method:

- Species; cell type (for *in vitro* cellular studies).
- Mode of administration (route, e.g., inhalation); single, multiple or chronic.
- Initial lung deposit (μg, Bq).
- Duration of experiment in days.
- Comment on method.

The third section contains details of the results:

- Box to tick if derivation of HRTM parameter values is feasible.
- HRTM parameter values if already derived: f_r (fraction dissolved rapidly) etc.
- Since detailed results are likely to be in the form of a table giving organ distribution at a number of times, the "Results" field gives a link to a separate spreadsheet, if available.
- Comment on results.

In some studies, complementary experiments were conducted, in which the material was also administered intra-gastrically or the radionuclide was administered intravenously to obtain information needed to interpret the results of the inhalation experiment. To accommodate this information the database includes *Ingestion* and *Injection Experiments* tables corresponding to the *Inhalation Experiments* table. The database can thus be used for a wide range of biokinetics experiments. The *References* table is linked to each table of *Experiments* through a "junction table", which enables each reference to be linked to any number of experiments (and *vice-versa*). By the time of the Workshop in May 1999, the database contained details of about 200 experiments from 75 publications, mostly related to uranium, plutonium and cobalt.

Intercomparison subgroup

At the first meeting of the Action Group, in March, 1997, recognising the effort that would be involved, and the close coordination required to carry out a successful exercise, it was agreed that a subgroup should be set up to organise the intercomparison. Hans Doerfel, Andor Andrasi and Guiseppe Taronni were proposed to be its members, and were later joined by Carlo-Maria Castellani. It was also recognised and agreed that the Subgroup would need to meet more often, and for longer periods, than the full Action Group. The programme of actions and meetings carried out by the subgroup is given in Section 4 of the Report. Because of the unexpectedly high response to the exercise, in terms of both the number of participants and the number of cases undertaken by each participant, following the November 1998 meeting, some other members of the Action Group agreed to assist with analysis and presentation of the results (Alan Birchall, Christian Hurtgen, Bernard Le Guen, Lennart Johannson).

1 Introduction

The determination of internal doses is an essential component of individual monitoring programmes for workers. It may also be needed for members of the public, who may have intakes of radionuclides in nuclear medicine and also in normal life following accidental releases of radionuclides into the environment. Assessment of internal doses can be divided into two phases, namely

- determination of the amount of radioactive material in the human body, in body organs or in wounds by direct measurements and/or by indirect methods such as excretion analysis or air monitoring,

- interpretation of the monitoring data in terms of intake and/or internal dose taking into account many influencing factors and assumptions, such as the physical and chemical characteristics of the radioactive substances, the mode of intake, the biokinetic and energy absorption processes, the individual parameters, etc.

The second phase is particularly important because of the number of variables and uncertainties involved. Although the International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) have published extensive tables of dose per unit intake (dose coefficients), these are default values based on assumptions about the intake parameters that may not be valid in specific situations. Determination of the intake and the resulting internal dose can, therefore, be approached in many different ways, depending on the amount and quality of the data, the skill of the dosimetrist, computational tools available, and the assumptions made. When a set of bioassay data is given to two different dosimetrists, it is likely that these data will be interpreted differently, that different methods and dosimetric models will be applied, and therefore different numerical solutions will be obtained. Thus, it is important for laboratories dealing with internal dosimetry to undergo performance testing procedures in both phases of internal dosimetry to demonstrate the correctness of methods applied and also the consistency of the results with those obtained by other laboratories.

Several intercomparison exercises have already been organised at national and international levels. The two phases of internal dose assessment have usually been treated separately. In the United States (U.S.), there have been several intercomparison studies, but the earlier ones focused more on a particular radionuclide or a particular issue. Among these were an intercomparison study on plutonium (Kathren et al. 1987), one on UF_6 (carried out after a cylinder rupture incident, NRC 1986), and one on computer software used for intake and dose calculations (LaBone 1991). In the plutonium intercomparison (Kathren et al 1987), six laboratories estimated systemic burdens of plutonium from urine data for 17 cases and reported relative standard deviations (RSD) in the range 20-90%.

In the United Kingdom (UK), the UK Internal Radiation Dosimetry Group reported in 1990 an interlaboratory comparison of methods used for estimates of systemic burdens of plutonium, with evaluation of four reference cases by six laboratories (Ramsden et al. 1990). A second intercomparison involved seven cases, which also included tritium, uranium and cobalt (Ramsden et al. 1992). About 80% of the results obtained in both exercises were within 40% of the median values. The variation in results was attributed to the process of expert judgement, data handling and the choice of models, with the process of expert judgement dominant for the tritium and cobalt cases.

The first major international intercomparison study was performed by EURADOS Working Group Number 6, supported by the Commission of the European Communities, CEC (Gibson et al. 1992). With the development of the European Union, which leads to free movements of workers between member countries, reasonable consistency or compatibility of methods for assessment of internal dose from intakes is becoming more important. In this CEC/EURADOS intercomparison study, five test cases covering ^{137}Cs, ^{90}Sr, ^{32}P and various actinides were used, and only nine institutes from six countries participated. Results showed that for most cases the relative standard deviation

(RSD) of the estimates of intake was about 30% and the RSD of the resulting dose estimates was about 40%.

The second CEC/EURADOS study has recently been completed (CEC report in press). It again involved five cases, this time covering intakes of uranium, plutonium, ^{241}Am, ^{60}Co and tritium. However, fourteen laboratories participated compared to nine in the first study. Even though newer ICRP models were available, such as the Human Respiratory Tract Model (HRTM), it was agreed among the participants that a standardised approach, the ICRP 26 and 30 methodologies, would be used in the assessments. Using this standardised approach, variation in the results of intakes and doses are reported to be similar to those of the first intercomparison. Subsequent analysis showed that significant differences would result if the new lung model were used.

In parallel to the intercomparisons performed under EURADOS, there are also other CEC intercomparisons. One of these, in connection with "The 1995/96 European Intercomparison of in vivo Monitoring Systems" involved artificially created test cases and also a large number of participants (forty-four) from more countries (nineteen). The dose evaluation is only one aspect, and not the principal one, of the intercomparison, which mainly deals with the performance of in vivo monitoring systems. The participants were asked to calculate doses on the basis of the incomplete information provided for four intake scenarios, involving selected radionuclides with well known biokinetics. The aim was to compare the methods and results of the dose assessment after the in vivo measurement. Participants used different ICRP biokinetic models. The RSD in the estimates ranged from 26% to 131%, due to the use of various ICRP standard models and the adoption of different underlying assumptions. The authors of the study concluded that there is an urgent need for standardised systems of methods and data handling to be applied to such dose assessments (M. Thieme, E.L. Hunt, K. Konig, A. Schmitt-Hanning and R. Godde "The 1995/96 European Intercomparison of in vivo Monitoring Systems", to be published).

The first major internal dosimetry intercomparison in the U.S. (Hui et al. 1994) was performed in 1992 by the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC). The five test cases used in the DOE/NRC study were the ones previously used in the 1992 CEC/EURADOS intercomparison (Gibson et al. 1992). The philosophy behind the DOE/NRC intercomparison focused more on assessing the inconsistencies of the results, whereas the CEC/EURADOS study focused on the harmonisation aspects. Therefore, there were several major differences in terms of implementation between the DOE/NRC and CEC/EURADOS studies. For instance, to simulate responses to realistic situations, participants were given only 2-3 weeks, a much shorter period than that allowed in the CEC study, to perform the intake and dose assessment. Once the results were submitted, no revisions were accepted. No formal discussions were held by participants to harmonise or revise the approaches or the results. Except for one test case, results show a slightly greater variation than that in the CEC/EURADOS study. Internal dosimetry software was identified as one of the factors contributing to the variation in the results.

In 1995, six institutes participated in another DOE intercomparison study, with five plutonium and tritium cases (Hui et al. 1997). The main difference from the first one was that the test cases are more related to work currently or previously performed at DOE facilities. A significant feature in this study is that some of the cases were generated artificially, and so the intakes and doses were known to the organiser. Some of the participating institutes used the newer ICRP models (ICRP Publication 56 onwards) and as a result the spread of results was much greater than that obtained previously, with RSDs of 21-73% for intake and 7-199% for dose. The focus of this study was not only on the different approaches used and variation of the results reported, but also to identify problem areas which may contribute to the discrepancies, for example, the resources available to assess the cases, and the lower participation in the more complex cases.

The latest, and previously the largest, world-wide intercomparison exercise was organised by the IAEA from 1996 to 1998 in the framework of a Co-ordinated Research Programme entitled "Intercomparison and Biokinetic Model Validation of Radionuclide Intake Assessment". For organisational and formal reasons, the number of participants was limited and participation was by

invitation. Twenty-six institutes from 22 countries from all over the world, plus the IAEA, were invited and 25 institutes actually participated. Nine realistic cases were prepared as test scenarios based on real, and in one case artificially-generated, data. The cases represented different characteristic scenarios for occupational exposures involving various radionuclides. The intake scenarios covered different pathways as well as single and multiple intake patterns. The participants were encouraged to apply, as far as possible, the recent ICRP recommendations on which the IBSS (Safety Series No. 115) IAEA publication is based. The scientific co-ordination and the final analysis of the submitted results were performed by three IAEA consultants.

Some participants did not submit results for all nine cases for several reasons, mostly because some cases were not relevant to their practices, and because they could not afford to spend the time and effort required for all the cases. The answers were investigated statistically, but there were some reservations about the procedures applied. The spread of results showed a similar picture to those of the previous exercises, and in some cases the ranges were even greater. There was an obvious positive correlation between the complexity of the case and the variation in the results. It also appeared that the selection of models and their parameters is a very critical factor in determining the final result, and so the use of the older and newer ICRP models can lead to very different results. However, the mixed use of different models and dose factors based on the older and newer ICRP recommendations (such as biokinetics from ICRP 30 and dose factors from ICRP 68) can lead to results which are not scientifically based and not self-consistent. Confusion was also caused by the simultaneous, and sometimes the mixed use of the previous and recent ICRP concepts of effective dose equivalent and effective dose, or dose equivalent and equivalent dose. At the end of the intercomparison exercise the whole programme and the analysis of results were discussed at a workshop where the participants could contribute to the final evaluation and conclusions drawn from the programme.

Besides stating the usefulness and success of this intercomparison exercise, the following main conclusions could be drawn, which are advised for consideration in future exercises of this kind:

- Reduce the number of case scenarios and focus on different well-defined aspects and goals of internal dose assessments. One approach could be to limit the number of variables to be selected by the participants, while the others are fixed.

- Introduce more artificially-generated case scenarios.

- Ask participants to include estimates of the uncertainty on the results in their responses.

- Compare the results which could be derived in an accidental situation from the very first measurement with those obtained later on after more detailed investigation of the case.

The IAEA demonstrated its ability to conduct this type of exercise. It has also expressed its intention to continue this kind of effort, to provide on a regular basis the opportunity for member states all over the world to check their capabilities, and to promote harmonisation on internal dose assessment. The whole intercomparison programme is described and published in a comprehensive report (IAEA-TECDOC-1071 1999).

These previous intercomparison exercises revealed significant differences in the approaches, methods and assumptions, and consequently in the results. In a Europe in which the free exchange of workers is promoted, much more effort must be devoted to the effective compatibility of doses assessed in different countries. To sum the doses assessed in different countries in the personal record of the worker should become a common procedure in record keeping. This underlines the importance of these intercomparison programmes as a key element of the harmonisation process towards unified common methods of evaluation.

2 Objectives

The main goals of the programme are:

- to provide opportunities for the participating laboratories to check the quality of their internal dose assessment methods,
- to compare different approaches in interpretation of internal contamination monitoring data,
- to quantify the differences in internal dose assessment
- to identify those models, parameters, assumptions, and fitting procedures which give rise to the largest variations in estimates of intakes and doses
- to open the intercomparison to any interested laboratory and to provide a forum for broad discussion of the results and methods which could help in more consistent interpretation of monitored data and in further improvement of the evaluation techniques
- to determine whether there is a need for providing general guidelines for applying the ICRP models and
- to determine whether the procedures applied in different European countries are consistent or whether there is a need for greater harmonisation of internal dose assessment procedures.

3 Organisation

The organisers recognised the importance of increasing the number of institutes participating in intercomparisons, and that it was particularly important to include those who had not previously participated in any intercomparison.

To implement the programme objectives the followings tasks were performed:

- The intercomparison was announced in several ways, particularly through the national radiological protection societies. There was no limit on the number of participants from each country and there was also no strict limitation to European countries. Finally, 62 institutes from 26 countries indicated their interest to participate, and 50 institutes from 18 European and 5 other countries actually participated. The final list of participants is shown in Annex B.
- Test scenarios were prepared for participants to evaluate. Seven realistic cases were prepared. A general structure for setting up the test scenarios was designed and shown in Annex C. The test scenarios designed were based either on real data or artificially generated data. The cases include different natural and artificial radionuclides and also range from simple straightforward cases to complicated cases with different exposure conditions. The following study cases were offered to the participants:

  Case 1: ^{3}H (HTO), continuous intake through skin

  Case 2: ^{90}Sr/^{90}Y, accidental intake, pathway unknown

  Case 3: ^{125}I, repeated intake, inhalation

  Case 4: ^{137}Cs, continuous intake, ingestion

  Case 5: natural activity (Po, U, Th), continuous intake, inhalation

Case 6: ^{239}Pu, single intake, inhalation

Case 7: ^{239}Pu, intake long time ago, time and pathway unknown

Guidelines, shown in Annex D, were provided to the participants on the list of information to be included in the response. The actual test cases offered to the participants are shown in Annex F.

- Case scenarios were distributed to the participants. The participants were given six months to evaluate the cases and to submit the results according to the guidelines.

- Data were compiled, analysed and discussed during two meetings in Budapest (February 1999) and Bologna (March 1999). Results for each cases are presented in Annex F. If needed, participants were requested to comment and to clarify any ambiguities.

- After receiving corrections and comments from the participants, the summary report was drafted after the meeting in Bologna.

- In May 1999 a workshop was organised in Weimar (Germany) to

  (i) distribute the draft summary report to the participants

  (ii) enable participants to check that their results were included correctly, and provide missing information. (Some participants offered revised estimates, but these were not accepted.)

  (iii) invite two participants for each case to present their own approaches to assessing the intakes and doses, following a summary of the cases and the distribution of results

  (iv) discuss the results,

  (v) draw conclusions on the intercomparison programme and

  (vi) give recommendations for future activities.

- Immediately following the Workshop, the Intercomparison Sub-Group, assisted by some members of the Action Group, met to develop further the draft final report.

- The final report was prepared as a report of the Forschungszentrum (Research Centre) Karlsruhe and distributed to the participants and to other interested bodies after the workshop. In addition, a summary of the intercomparison will be prepared for publication in the open literature.

4 Results

4.1 General

Guidelines for presenting the results, as shown in Annex D, were provided along with the case scenarios to the participants. These guidelines serve three purposes. First, participants were encouraged, not required, to evaluate as many case scenarios as possible. Second, if more than one approach were used, participant should specify the preferred approach and answers. Last, and the most important, participants were required to provide the key information as listed in Annex F to facilitate compilation and analysis of their response.

In terms of the participation rate for each case scenario, it apparently varies with the complexity of the exposure scenario. This may due partly to the fact that some of the selected case scenarios may involve exposure to radionuclides considered rare in some participating countries. In addition, some of the cases scenarios may be complicated enough that efficient evaluation may require fairly sophisticated computations tools which may not be available to some participants. However, this intercomparison represent an opportunity for many participants to gauge their performance against others and they are encouraged to do so. The following list shows the number of responses for the seven cases.

Case 1 (^{3}H):	41 responses
Case 2 (^{90}Sr/^{90}Y):	38 responses
Case 3 (^{125}I):	38 responses
Case 4 (^{137}Cs):	43 responses
Case 5 (Po, U, Th):	20 responses
Case 6 (^{239}Pu):	32 responses
Case 7 (^{239}Pu):	30 responses

Generally, the highest response rate is 43 out of 50 for Case 4 and the lowest is 20 for Case *5*. The response rate is close to 80 % for the cases related to fission and activation products, 60 % for the ^{239}Pu-cases and 40 % for the case dealing with natural radioactivity.

It is obvious that most participants in most case scenarios attempted more than one approach to evaluate the test cases, even though many of them only include a single approach in their responses. For those providing results for more than one approach, usually a preferred one was specified.

In terms of the presentation of the results, the responses from participants varied greatly. While some participants followed the Guidelines and provided the key information to facilitate compilation and analysis, many others did not. Some of the responses are extremely detail and follow a clear format, probably dictated by the local requirements. Some others are too brief (some as short as a single page) and with insufficient data. Responses with insufficient data or ambiguous information not only increase the time and effort in compilation and analysis, it also increase the chance of error in these processes. In these case, clarifications are requested from participants and this increase the processing time and effort.

During the compilation of the results, it was observed that there was some confusion of the older and most recent dosimetry concepts being used by the participants. The guidelines requested the resulting dose be reported in committed effective dose, E(50), as described in ICRP60. However, only a limited number of participants possess the more recently developed computation tools which allow such calculations. If a particular participant is using the older ICRP30 approach, then the resulting doses are committed effective dose equivalent, CEDE. These two concepts are technically different. However, for the purpose of this intercomparison, they are both consider the same, as E(50). The availability of more recently developed computational tool also affect the choice the biokinetic and lung models. For the ICRP26 lung model, the clearance classes are D, W, and Y. Whereas for the ICRP66 respiratory tract model, the clearance classes (absorption types) are F, M and S. The clearance classes were listed as the participants described. It is expected that, only until the more recently developed computational tools which contains all the recent models are made available to all, these confusions will continue.

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

addition, the geometric mean and also the geometric standard deviation was included as it reflects better the statistical variation of the results and may provide a better graphical representation of the data (see Section 4.2)

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

4.2 Procedure for selecting data for statistical evaluation

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

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

A second important point is that we know the meaning of the data and we are able to recognize data with low coherence in relation to the others and the low number of data make it possible this direct examination. We only need not an automatic procedure for rejection, but a method to verify if one or a little number of data can completely distort the statistical parameters of the distribution.

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

Adopting these concepts the basic starting points are:

- The results belong to a single log-normal distribution
- Probability concepts are used to test if one or some specific results are pertaining to this distribution

As a conclusion, the procedure should be based on the probability that the specific value is belonging to the distribution of the other data: if this probability is lower than a fixed value we conclude that it is not and we will not use for statistical evaluation (not "reject"). The choice of the confidence interval is based on the size of the sample in each set or subset of data (ranging from 15 to 43).

Based on this assumption the following procedure is adopted:

1. Calculation of the log-values of all the results, Xi
2. Calculation of the parameters of the log-normal distribution of all data: Geometric Mean (GM) and Geometric Standard Deviation (GSD)
3. Calculation of the deviation in unit of GSD for all values: $z = (\ln Xi - \ln GM)/\ln GSD$

4. Identification of all results with a deviation, z in step 3, of more than ± 2.5 (corresponding to 98.8% confidence interval). These values are considered as possible "outliers", and will not be used for the final statistical evaluation
5. Repetition of steps 2, 3 and 4 without the "outliers" identified in step 4 as long as the distribution parameters become stable
6. The final parameters of the log-normal distribution, GM and GSD, reported in the tables will be the stable values found in step 5

When applying this procedure it may happen that one result is identified as outlier when considering the whole set of results, but it is not an outlier when considering some subset of the results (for instance the subset of results based on urine or feces, respectively, or the subsets of results based on the old or the new ICRP models, respectively). On the other hand it may happen that one result is identified as an outlier in a subset but not in the whole set of data, because the GSD can be much larger in the whole set than in the subset. The organisers are aware of this problem. However, the procedure is considered to be the only practicable-one.

4.3 Results on cases

4.3.1 Continuous intake of Tritium

This intake scenario describes a case which is uncommon in the sense that the intake pathway through the skin is not very typical. However it is a good example of a minor source of exposure of the public, being due to internal contamination when wearing wrist watches having plastic cases with luminous dials containing tritium. Since this was a voluntary experiment, the exposure conditions were quite well known except for the physical and chemical characteristics of the contaminant taken in through the skin. Tritium is a low-energy beta-emitting radionuclide. When it enters the body, most is dispersed in the body fluids, and it subsequently leaves the body, mainly in urine, with the same concentration. Internal contamination can therefore be assessed on the basis of tritium activity measurements in excreted urine, which are usually made by liquid scintillation counting.

In the present case, 24-hour urine samples were collected every day, starting from the day on which the experiment began, for 29 days of continuous (day and night) exposure. After removing the watch, the urine sampling continued for a further 21 days to follow the declining tritium concentration in the body. The duration of the experiment was thus a total of 50 days. The urine measurements showed that the activity concentration started to increase immediately after the experiment began and reached a maximum value after about 14 days. The activity concentrations over the next 15-day time period fluctuated around this level – which could be regarded as a secular equilibrium state – when the intake rate and the excretion rate, considering all pathways, became identical. In the latter part of the experiment, after the watch had been removed, the daily excreted tritium activity decreased according to the biokinetics of the person. In the description of the scenario, the data relating to the daily average tritium concentration in urine were given in Bq/l, together with the uncertainties due to 1 standard deviation of the activity measurements. The variation with time of the measured activity concentration values in the 24-hour urine samples for the entire experiment period is shown in Figure 4.3.1.1.

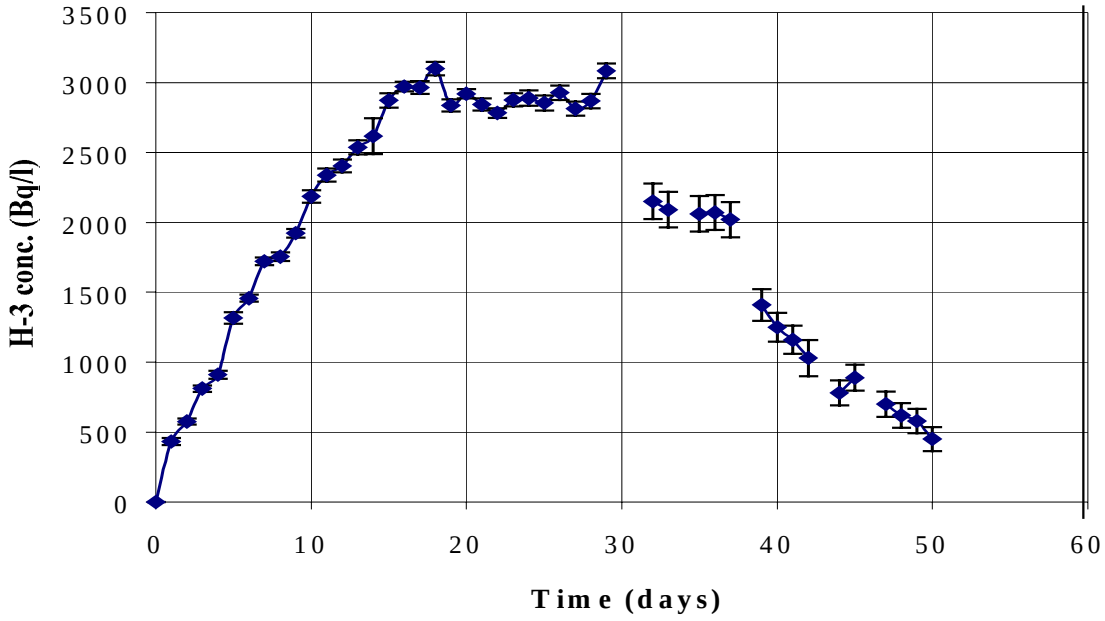


Fig. 4.3.1.1: Variation of measured tritium concentration in 24-hour urine samples

In this case, personal data relating to the sex, age and especially to the weight can also be regarded as important information to be considered. The participants were asked to calculate the average daily intake during the period of exposure, the daily effective dose rate during the equilibrium state and the committed effective dose (CED), E(50) due to the total intake.

Most of the 50 participants submitted results on this case, and 41 answers were received. There were participants that provided more than one set of results, obtained by alternative approaches. However, only one set of results was considered from each participant in the final evaluation. Some answers were not clear enough to enable the procedure chosen to be understood, but most of the participants provided enough information about their approaches. Nearly all the participants calculated the average daily intake value from the mean urine activity concentration during the equilibrium period, considering the body weight, assumed water content of the body, the volume of urine assumed to be excreted daily, and the urinary fraction of the total water volume leaving the body. Two participants (ID 15 and 31) interpreted the measurements assuming two different intake patterns during the equilibrium period. The corresponding average effective dose rate in the equilibrium period could be derived from the tritium content in the body using the appropriate SEE value calculated for tritium. For the CED (E(50)) due to the total intake, the approaches differed depending whether the ICRP recommended dose coefficients were used or experimentally-measured values were adopted for calculating the dose contribution in the period after the intake. In the latter case a biological half-life was derived, assuming a single exponential term. Its value was in the range 5.7 – 6.5 days or 7.9 – 10 days depending on whether the data in the increasing or decreasing period respectively were considered. It must be mentioned that the biological half-life determined from measured data in the increasing period is less reliable than that derived from data in the decreasing period following steady-state conditions.

This tritium case is relatively simple in terms of calculation because the exposure conditions are well known and sufficient monitoring data are available. Therefore, it was expected that the results submitted would be close to each other, although the average daily intake values ranged between 106 and 20 500 Bq. When applying the accepted procedure for establishing the so-called outliers (ID 11 and 39) this range became much narrower (6 369 to 20 500 Bq). This means that almost all results

differed by a factor of not more than three, which is quite reasonable compared to the previous intercomparison exercises. The geometric mean (GM) without the outliers was found to be 12 236 Bq with a geometric standard deviation (GSD) of 1.320. For the average daily effective dose rate, the spread of results shows distribution patterns similar to the intake rate values. If we disregard the outlying low daily effective dose rate values of 0.011, 0.062 and 0.0045 (ID 28, 35 and 39), values of 0.170 μSv for the GM and 1.362 for the corresponding GSD are obtained. Results with similar spreads were submitted for the committed effective dose (CED) for which all the values ranged from 0.139 to 10.7 μSv, with 5.29 μSv as GM and 1.163 as GSD (disregarding the outlying results). It must be mentioned that, for CED, the procedure gave as many as seven outliers, and so the final range of the data was within a factor of 2. The very low data for ID 39 are probably due to typing or trivial calculation errors. All submitted results can be seen in the Annex (Table A1.2.1) where the outlying data are indicated with shadowed background. The main statistical parameters are summarised in Table 4.3.1.1.

It turned out from the answers that most of the participants – at least those who provided this information – used computer codes for the evaluation which were either commercially available ones or home-made programs. A list of the computer codes used exclusively or partly by the participants is given in the Annex E.

Table 4.3.1.1: Main statistical characteristics of the submitted results

	Average daily intake [Bq]	Average daily effectivedose during equilibrium [μSv]	Committed effective dose due to total intake [μSv]
Geometric mean	12236	0.170	5.29
Geometric standard deviation[1)]	1.320	1.362	1.163
Arithmetic mean	12713	0.177	5.351
Arithmetic standard deviation	3678	0.054	0.831
Minimum[2)]	106	0.0045	0.139
Maximum[2)]	20500	0.346	10.7

1) dimensionless

2) including outliers

The answers of the participants relating to the models used showed broad variety. There were participants that indicated the exclusive use of the older ICRP recommendations based on ICRP Publication 30 (ICRP 54 and 56) while others referred only to the application of the more recent ICRP publications (ICRP 60, 67 and 71). However there were several participants that mentioned the use of both older and more recent ICRP publications, mostly referring for biokinetics to the previous ones (ICRP 30 and 54) and taking the dose coefficients from the recent ICRP Publications (ICRP 67, 68, 71 and 78). Two participants – both using the CINDY program – indicated the use of the Johnson lung model. The most characteristic model parameter which was reported by the participants was the retention time. This was either taken from the ICRP Publications as an accepted default value or

derived as a biological half-life from the experimentally-determined urine activity concentrations in the increasing or decreasing periods.

The great majority of the participants used all 50 monitored data but five participants calculated the requested quantities from the data of the first 29 days. It is interesting to illustrate the daily effective dose versus daily average tritium intake values, where the large spread of data reflects mostly the different ways in deriving these two quantities (Fig. 4.3.1.2).

It turned out from the evaluation of this case that using the same computer code does not necessarily mean good agreement of results. For example, LUDEP users gave values from 106 to 20300 Bq/day intakes. However, the daily intake values averaged separately for LUDEP and CINDY users do not differ significantly from each other. It can generally be stated that no correlation was seen between the choice of computer codes, models, experimental data or any other known parameter and the calculated results. The observed spread of results is instead due to the different assumptions made, the procedures applied, and the sources of the parameter values used.

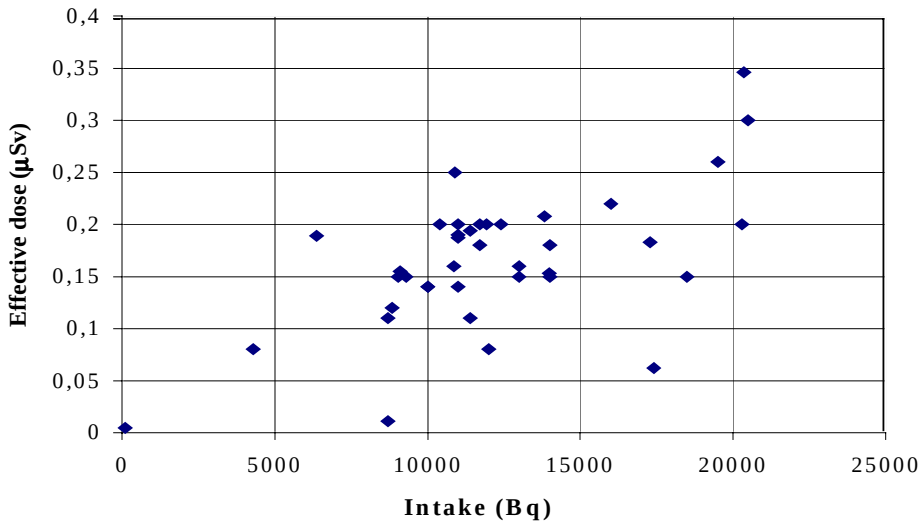


Fig. 4.3.1.2: Daily effective dose versus daily intake

The frequency distributions around the geometric means of the results for the three requested quantities, together with the standard deviations of the individual values from these geometric means, are shown in Figs. 4.3.1.3 to 4.3.1.8.

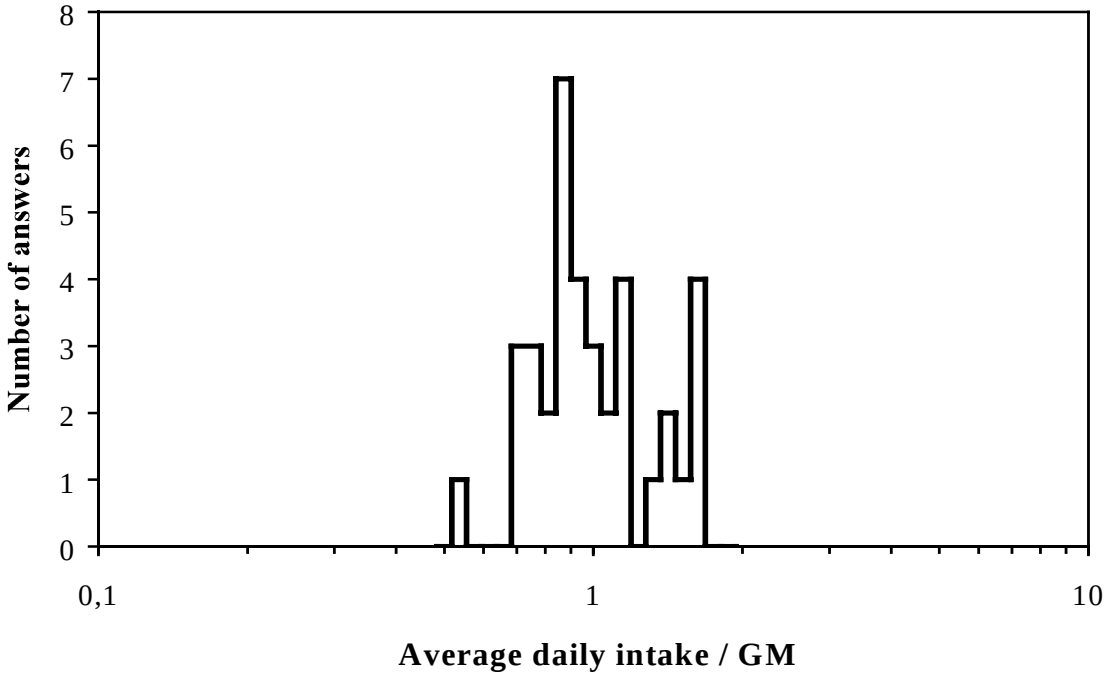


Fig. 4.3.1.3: Frequency distribution of the results: Average daily intake normalised to the geometric mean (GM = 12236 Bq; GSD = 1.32; 98.8% C.I. = 6112 – 24495 Bq)

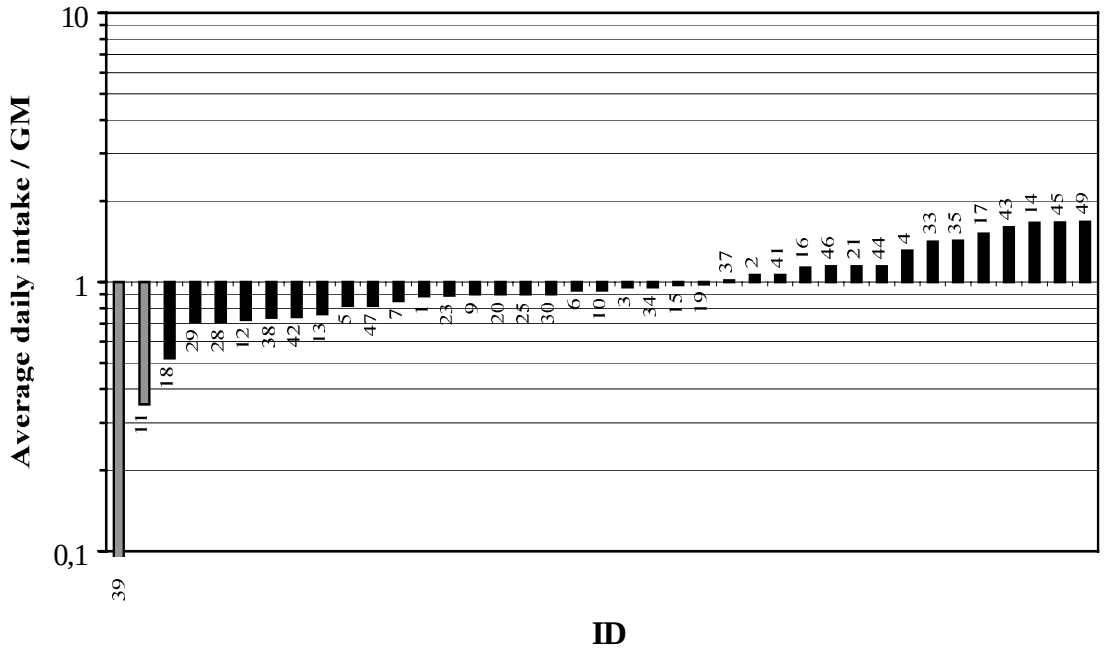


Fig. 4.3.1.4: Results of the individual participants (ID): Average daily intake normalised to the geometric mean (GM = 12236 Bq; GSD = 1.32; 98.8% C.I. = 6112 – 24495 Bq)

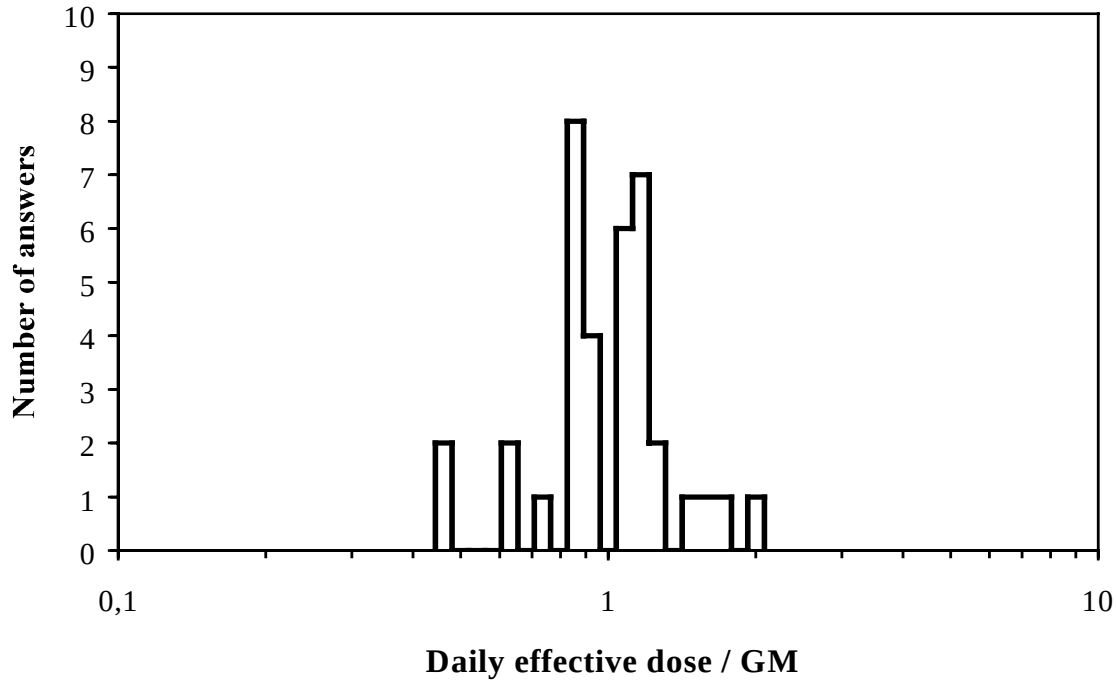


Fig. 4.3.1.5: Frequency distribution of the results: Daily effective dose normalised to the geometric mean (GM = 0.170 µSv; GSD = 1.362; 98.8 % C.I. = 0.079 – 0.368 µSv)

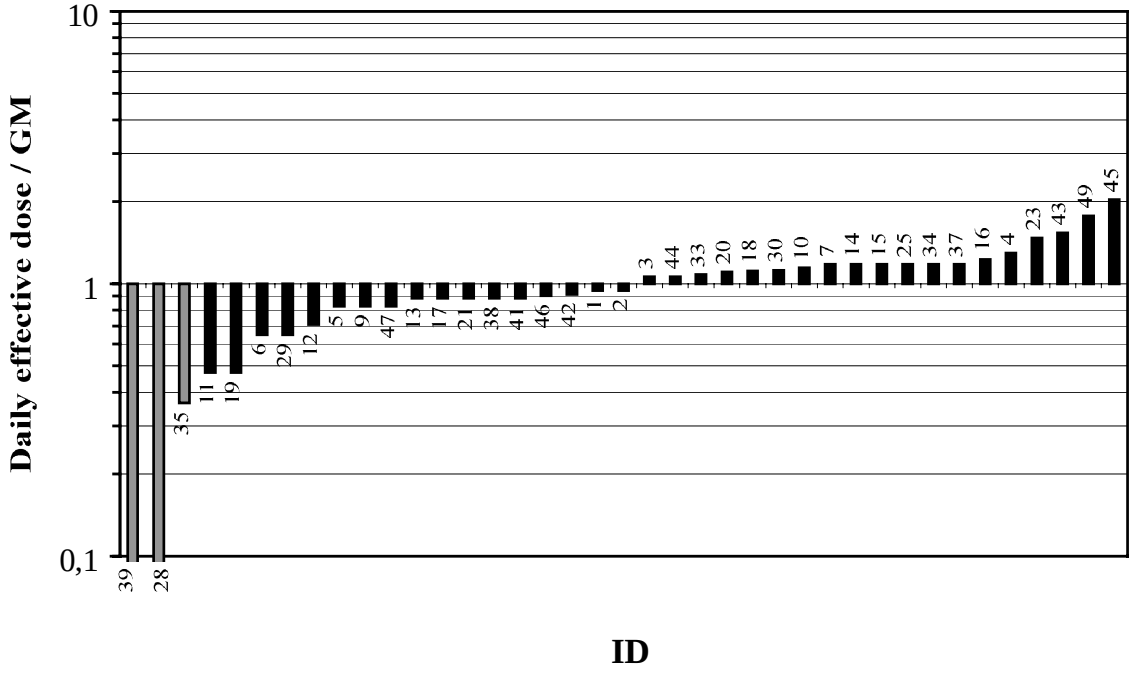


Fig. 4.3.1.6: Results of the individual participants (ID): Daily effective dose normalised to the geometric mean (GM = 0.170 µSv; GSD = 1.362; 98.8% C.I. = 0.079 – 0.368 µSv)

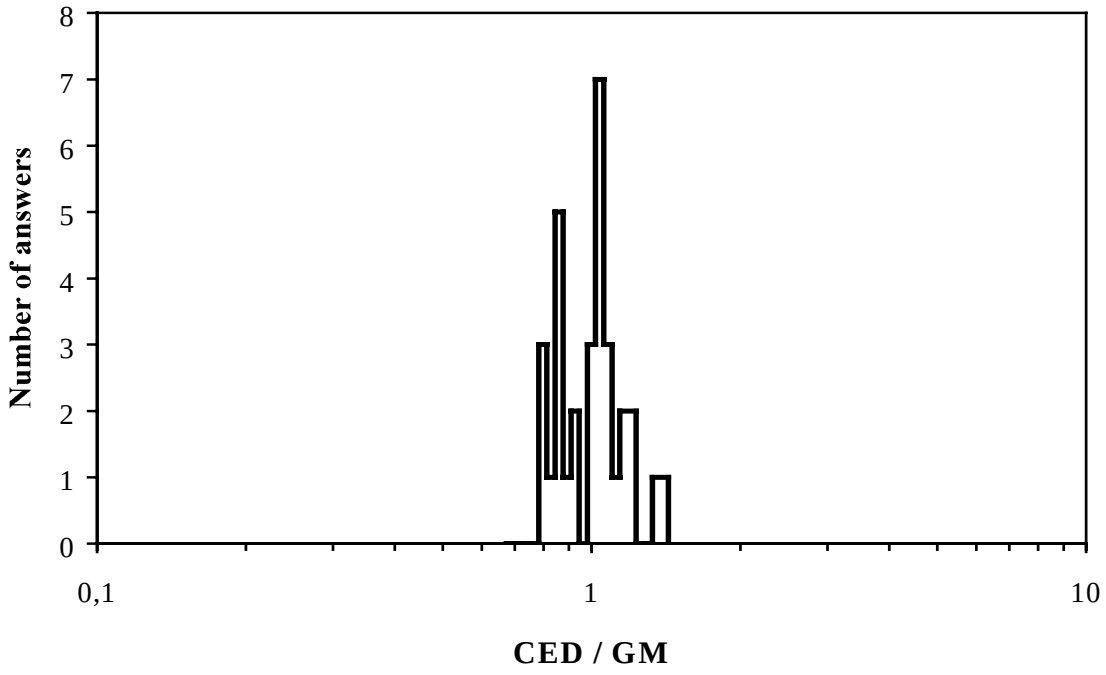


Fig. 4.3.1.7: Frequency distribution of the results: Committed effective dose normalised to the geometric mean (GM = 5.29 µSv; GSD = 1.163; 98.8% C.I. = 3.63 – 7.72 µSv)

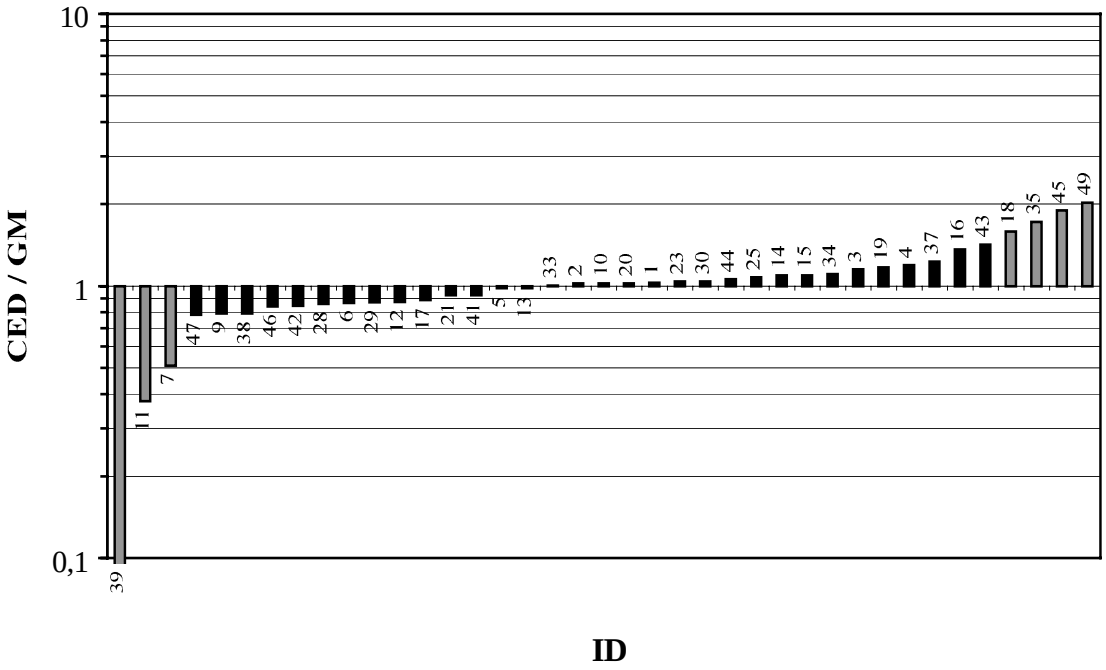


Fig. 4.3.1.8: Results of the individual participants (ID): Committed effective dose normalised to the geometric mean (GM = 5.29 µSv; GSD = 1.163; 98.8% C.I. = 3.63 – 7.72 µSv)

4.3.2 Incidental intake of $^{90}Sr/^{90}Y$

This case is related to a real case, which occurred at a research centre in Central Europe. A previous contamination was discovered as a result of a visit to a research reactor, some time after the most probable period of intake. The special features of this case are that it involves a lady from the general population and urine measurements are provided. The exact time of intake and the duration of intake (acute or chronic) are unknown, but the period can be restricted to 13 days from 24 January to 6 February 1996.

In the case description it is said that important surface contamination (ranging from 50 to 100 kBq) was detected on clothing, but no skin contamination was found. As far as the pathway of intake is concerned, it is suggested that it can be assumed to be ingestion. As further information it is also suggested that radiological equilibrium between ^{90}Sr and ^{90}Y can be assumed. The chemical form of the compound is stated to be soluble, because no further information is available. Seven urine measurements are provided spanning from 59 to 739 days after the beginning of the possible intake period. Absolute uncertainties on them expressed as 1 standard deviation are also reported. Fig. 4.3.2.1 shows the original data with the corresponding uncertainties.

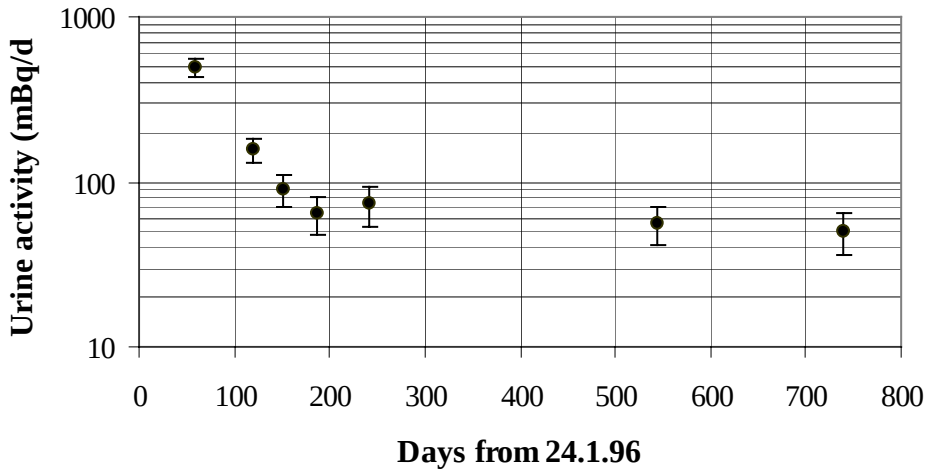


Fig. 4.3.2.1: Original data from the case description.

Thirty-eight participants answered the case: the maximum response is 4 pages while the minimum is ½ page. The participants were requested to provide their own evaluation of intake of ^{90}Sr [indicated in the following with I] and of committed effective dose due to ^{90}Sr and ^{90}Y [E(50)]. The only note reported for the comprehension of the case scenario is related to one participant (ID 46) who found a conflict between what is said in point 5.1 "The data given in the table below refer to the activity of ^{90}Sr in radiological equilibrium with ^{90}Y." and the title of column 2 of the table "^{90}Sr-concentration". He therefore assumed that the excretion data relates to the ^{90}Sr alone. Also, another participant (ID 44) did not take into account the simultaneous intake of ^{90}Y.

Using the procedure for selecting data for statistical evaluation described in Chapter 4.2, it was possible to find, in both sets of values, 4 data not pertaining to the general distribution. These were ID 2, 23, 42, 44 for intake, and ID 18, 37, 39, 44 for E(50).

As far as the intake values are concerned, one participant (ID 44) reported an intake approximately one order of magnitude greater than the others did. Two participants (ID 2 and 23)

found a value of intake approximately 3 times greater, perhaps due to modifying the middle component of the excretion model (ID 2 used 22 d instead of 44 d as the half time). One participant (ID 42) reported a value of intake approximately equal to half the values reported by the others, but no further information is given to enable the reason for this to be understood.

The explanation of the dose outliers is related to the use of dose coefficients approximately 1 or 2 orders of magnitude higher then the general mean (ID 18 and 39 respectively) or to a dose coefficient 1 order of magnitude lower, due to the assumption of $f_1 = 0.01$ (ID 37). In the case of the participant ID 44 it is the greater estimate of the intake that brings the value out of the main distribution, even if using an acceptable dose coefficient.

The statistical results related to the main distribution for the intake are: number of data = 34, geometric mean (GM) = 2696 Bq, geometric standard deviation (GSD) = 1.37, arithmetic mean (AM) = 2829 Bq, arithmetic standard deviation (ASD) = 907 Bq. For the committed effective dose (E(50)) due to ^{90}Sr and ^{90}Y the results are as follows: number of data = 34, GM = 0.093 mSv, GSD = 1.78, AM = 0.110 mSv, ASD = 0.076 mSv. The range is 965 – 25000 Bq for intake (ratio max/min = 25.9) and 0.004 – 7.6 mSv for committed effective dose (ratio max/min = 1767)

The following comparisons of subsets of data are performed on each data set without considering the corresponding outliers i.e. without ID 2, 23, 42, 44 for intake and ID 18, 37, 39 and 44 for E(50). The majority of participants used acute ingestion as the pathway and mode of intake. Some participants (ID 11, 13, 32, 42) used “acute inhalation” as the pathway of intake. Thus an analysis of the differences between the two sets of data is reported here. For intake the value of ID 42 is omitted because of its identification as an outlier.

Table 4.3.2.1: Statistical evaluation of the results with respect to the pathway of intake

	Intake (Bq)		E(50) (mSv)	
	Acute ingestion	Acute inhalation	Acute ingestion	Acute inhalation
N participants	27	3	26	4
GM	2650	2809	0.111	0.090
GSD	1.41	1.18	2.63	2.89

Table 4.3.2.2: Statistical evaluation of the results with respect to the mode of ingestion

	Intake (Bq)		E(50) (mSv)	
	Acute ingestion	Continuous ingestion	Acute ingestion	Continuous ingestion
N participants	26	3	25	4
GM	2679	3218	0.114	0.091
GSD	1.41	1.09	2.65	2.58

Three participants (ID 1,2, 6 and 7) used continuous instead of acute ingestion. A similar evaluation permits us to illustrate these results (data related to intake for ID 2 is omitted as an outlier).

The majority of participants used the period 30–31 January – 1 February as the date of intake i.e. the middle of the possible period of intake. The participants are divided into the following sub-sets related to the date of intake (outliers are not taken into account):

Intake:	24 January:	ID 17
	30 January:	ID 9, 15, 20, 21, 28, 33, 34, 39, 47
	31 January and 1 February:	ID 5, 11, 12, 13, 18, 25, 30, 35, 37, 38, 41, 43, 45, 49
	4-6 February:	ID 3, 14, 19, 46
E(50):	24 January:	ID 17, 42
	30 January:	ID 9, 15, 20, 21, 28, 33, 34, 47
	31 January and 1 February:	ID 5, 11, 12, 13, 25, 30, 35, 38, 41, 43, 45, 49
	4-6 February:	ID 3, 14, 19, 46

Table 4.3.2.3: Statistical evaluation of the results in terms of intake with respect to the assumed date of intake

Date of intake	24/01/96	30/01/96	31/01/96 and 01/02/96	4-6/02/96
N participants	1	9	14	4
GM	2670	3005	2484	2214
GSD	-	1.34	1.34	1.26

Table 4.3.2.4: Statistical evaluation of the results in terms of committed effective dose with respect to the assumed date of intake

Date of intake	24/01/96	30/01/96	31/01/96 and 01/02/96	4-6/02/96
N participants	2	8	12	4
GM	0.069	0.113	0.079	0.068
GSD	1.22	1.61	1.46	1.29

As can be noted, except for the two values related to 24 January as date of intake, there is a decrease in the evaluated mean intake, and consequently the committed effective dose, as the assumed date of intake is later: 30, 31 January or 4-6 February. The overall range of values of dose coefficient used goes from $2.688.10^{-9}$ to $3.04.10^{-6}$ Sv/Bq, and so the ratio max/min is more than 3 orders of magnitude. By elimination of the outlying values with respect to E(50) the remaining 34 values give GM= $3.288.10^{-8}$ Sv/Bq GSD= 1.55. It is difficult to make a listing of models used to deal with the case. Models can be used to: evaluate excretion and retention function, deal with the GI-tract, calculate intake, calculate and use dose coefficients. A summary is reported in the table of Annex F2.2.

For comparison purposes the participants are collected into three categories with respect to the models used.

ICRP 20-30-54: ID 1,9,11,13,15,17,18,21, 25,28,33,34,41, 47

ICRP 67- 68-72: ID 3,4,5,7,12,29,35,37,38,43,45,46,49

Johnson alkaline earth model: ID 6,19,20,30

Table 4.3.2.5: Statistical evaluation of the results in terms of intake with respect to the models used for evaluation

	ICRP 20-30-54	ICRP 67- 68-72	Johnson model
N participants	14	13	4
GM	3146	2388	3020
GSD	1.40	1.51	1.11

Table 4.3.2.6: Statistical evaluation of the results in terms of committed effective dose with respect to the models used for evaluation

	ICRP 20-30-54	ICRP 67- 68-72	Johnson model
N participants	16	12	4
GM	0.097	0.078	0.105
GSD	1.98	1.41	1.10

It seems that Intake and CED values estimated by the old models are greater than those evaluated by means of the new ones. Definitive statistical evidence of this difference is not possible to obtain because of the spread of data. It seems that the Johnson model gives, on average, values that are closer to those calculated for ICRP 20-30 and 54 models than those for the other ones. Participants ID 6, 19, 20 and 30 all used the Johnson model in the computer code CINDY and have practically the same values (GSD less than 1.2).

As a standard approach, 21 participants stated that they used f_1=0.3. Only ID 37 used f_1=0.01 for Sr-titanate and this gives a dose coefficient 1 order of magnitude less than the others. Only two

participants used age-dependent dose coefficients for 15-y-old male or females. ID 38 used f_1=0.4 as indicated for a 15-y-old man. ID 44 used the dose coefficient for females.

Only 8 participants (ID 4, 5, 9, 11, 15, 17, 32, 34) reported uncertainties in intake and dose results (see Table 4.3.2.7). As can be seen, a uniform way to indicate uncertainties is far from general in evaluation of intakes and doses. Perhaps the object of a future intercomparison would be how to manage the different ways of dealing with uncertainty in internal dosimetry. The uncertainty in CED, when reported, is the same as that of the intake: this means that the dose coefficient is considered to have negligible uncertainty, except for participant ID 15 for which the dose coefficient introduces as much uncertainty as the uncertainty of the estimate on the intake.

Table 4.3.2.7: Uncertainties as reported by the participants

ID of participant	Uncertainty in Intake evaluation (± %)	Uncertainty in E(50) evaluation (± %)	Comment
4	9.6	9.6	Range due to intake date (beginning – end of the period)
5	37	37	95% CI : takes into account uncertainties in measured data and differences between data and fitted excretion function
9	22	22	-
11	15.3	-	-
15	25	50	-
17	14	14	68.3% CI
32	6.4	-	Uniform absolute error in measured data
34	14.3	-	-

Table 4.3.2.8: Statistical evaluation of the results with respect to the data used for evaluation

	Intake (Bq)			E(50) (mSv)		
	All data	Initial values	Late excretion values	All data	Initial values	Late excretion values
N	25	2	2	25	2	3
GM	2824	1616	3162	0.082	0.074	0.150
GSD	1.31	1.44	1.91	1.61	1.28	2.25

The majority of participants (ID: 1, 4, 5, 6, 7, 9, 11, 12, 13, 17, 18, 19, 20, 25, 28, 29, 30, 33, 34, 35, 41, 42, 43, 45, 46, 49) used all seven data. In the intake evaluation ID 42 is not considered (identified as an outlier); in the E(50) evaluation ID 18 is not considered (identified as an outlier). Three participants used the late excretion (last 2 or 3 data: ID 2, 15, 21); in the intake evaluation ID 2 is not considered (identified as an outlier). Two participants used the first 4 data (ID 14 and 38).

It seems that the participants who used the late excretion data have values significantly greater than those of all the others. Conversely, those who used only the first data presented lower values than those who used all the data.

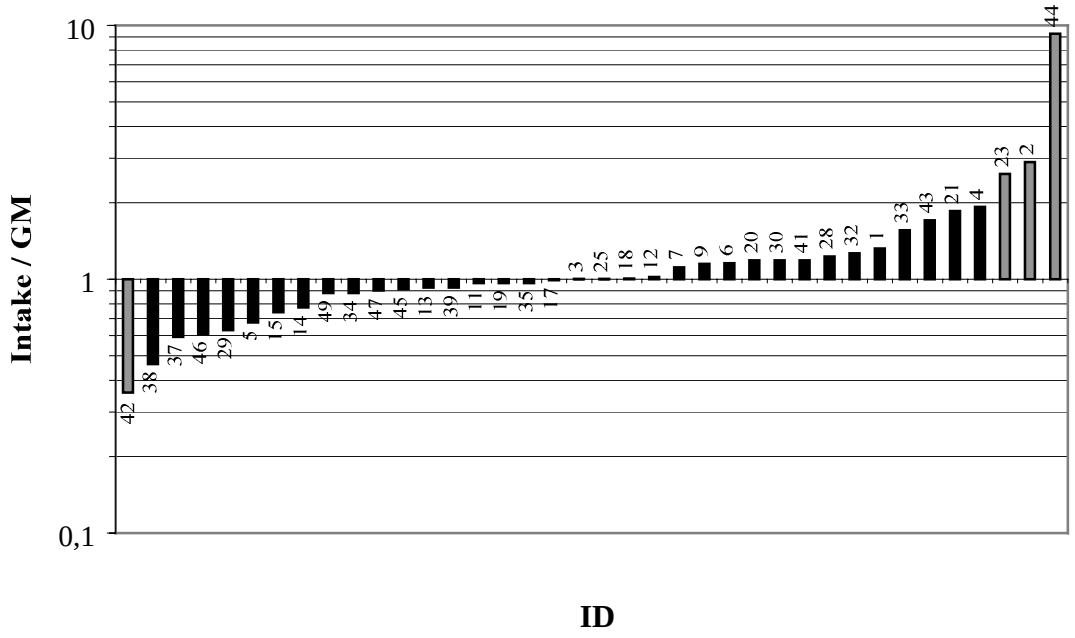


Fig. 4.3.2.2: Results of the individual participants (ID): Intake normalised to the geometric mean (GM = 2696 Bq; GSD = 1.37; 98.8 % C.I = 1227 – 5923 Bq)

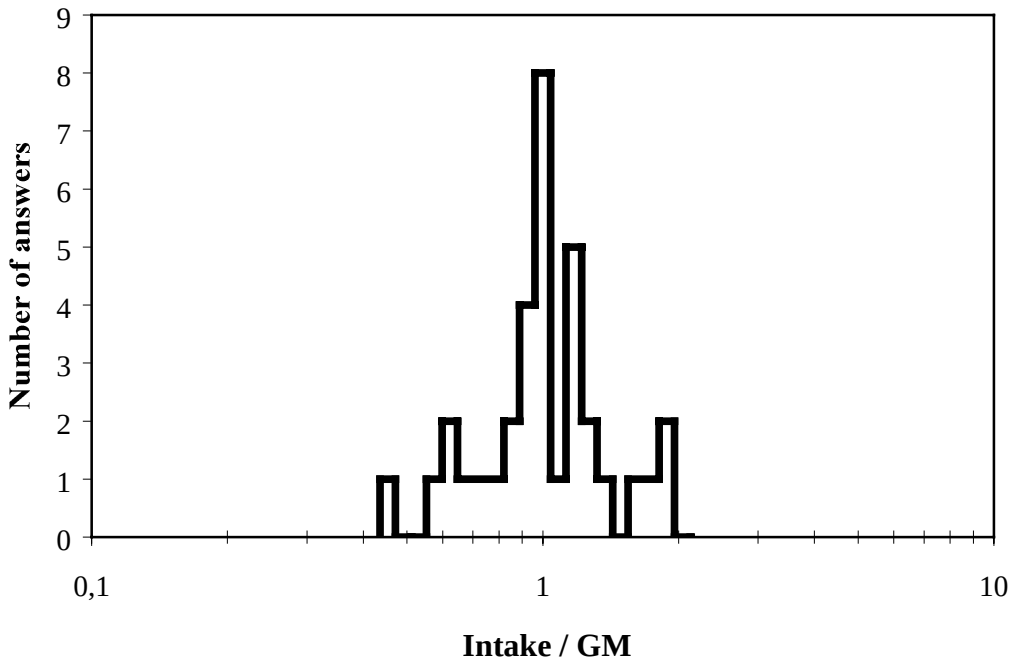


Fig. 4.3.2.3: Frequency distribution of the results: Intake normalised to the geometric mean (GM = 2696 Bq; GSD = 1.37; 98.8 %C.I = 1227 – 5923 Bq)

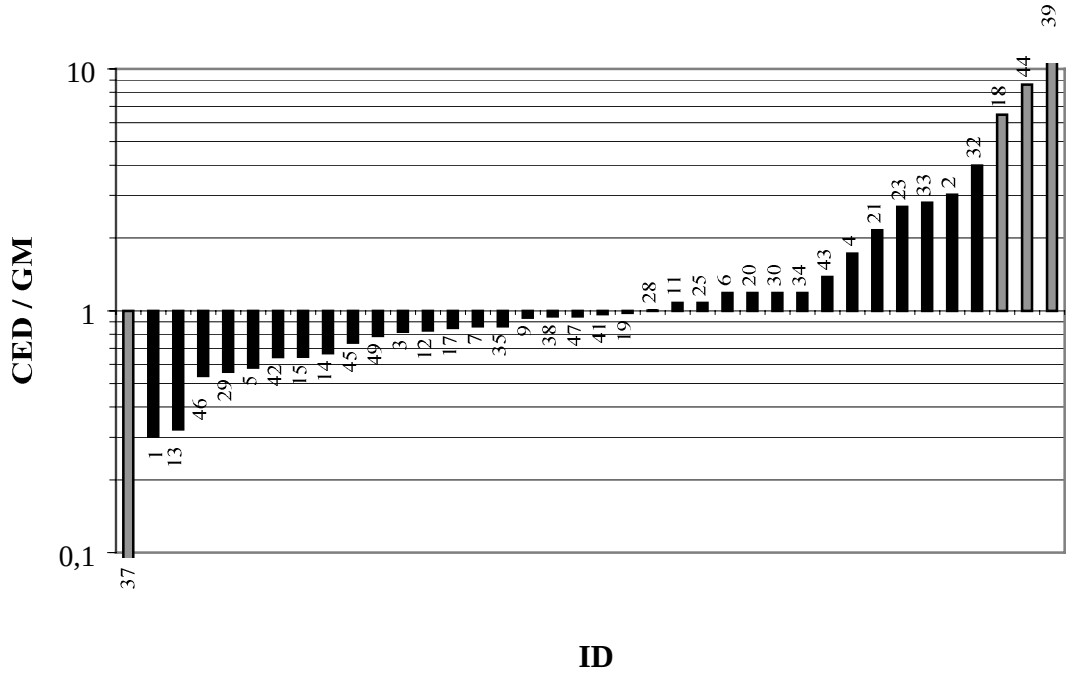


Fig. 4.3.2.4: Results of the individual participants (ID): Committed effective dose normalised to the geometric mean (GM = 0.093 mSv; GSD = 1.78; 98.8 % C.I = 0.022 – 0.393 Bq)

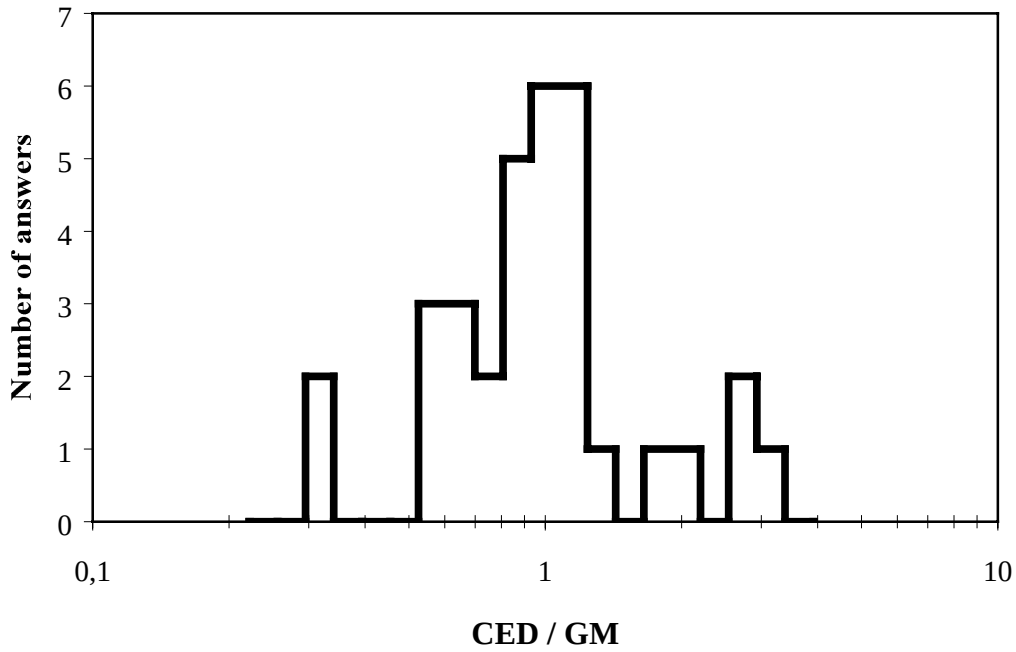


Fig. 4.3.2.5: Frequency distribution of the results: Committed effective dose normalised to the geometric mean (GM = 0.093 mSv; GSD = 1.78; 98.8 % C.I = 0.022 – 0.393 Bq)

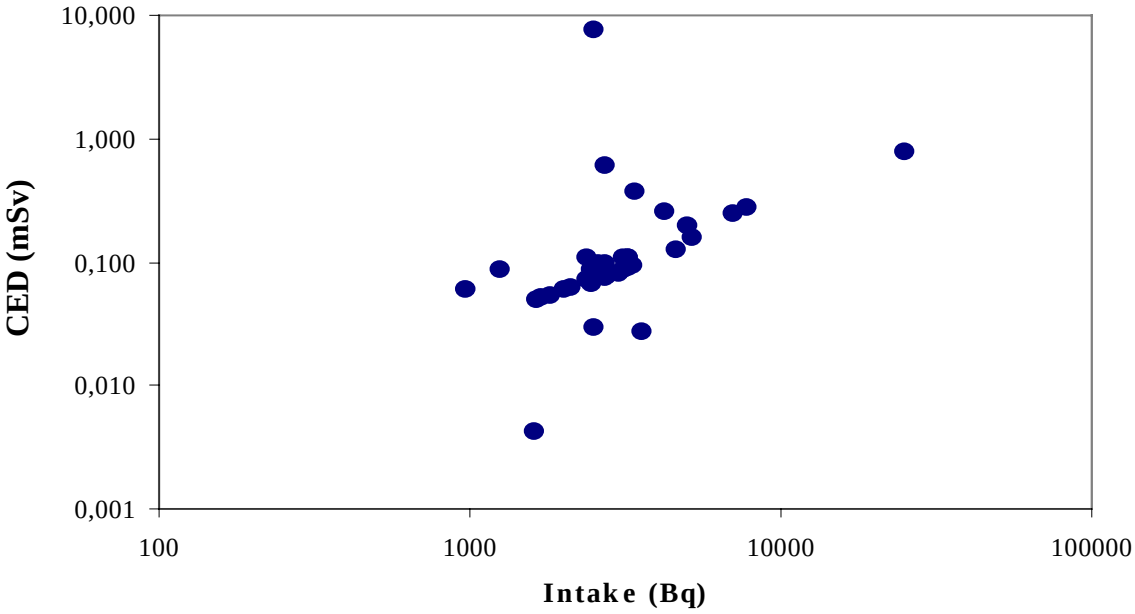


Fig. 4.3.2.6: Committed effective dose versus intake

Conclusion: In the evaluation of this case a large spread of data for intake and dose has not been demonstrated: the majority of estimates of intake (not considering the outliers) are between 1250 and 5200 Bq and the majority of dose evaluations are between 0.028 and 0.37 mSv. Four participants have been identified as outliers (ID 2, 23, 42, 44) for intake, and four, (ID 18, 37, 39, 44) for committed effective dose. Participant ID 44, due to an anomalous evaluation of intake (25000 Bq), was also an outlier for committed effective dose even though using an acceptable dose coefficient. Participant ID 37 was an outlier for dose evaluation due to using a dose coefficient that is approximately one order of magnitude less than the others, due to his choice of compound type and value of f_1=0.01. Participant ID 39 has a correct evaluation of intake but used a dose coefficient that is 3 orders of magnitude greater than all the others.

4.3.3 Repeated intake of ^{125}I

This ^{125}I contamination case is representative of a very frequently occurring situation where routine monitoring results have to be evaluated and interpreted in terms of intake and dose. Since many of the iodine compounds of interest are volatile, there is a high probability of intake by inhalation during work with radioiodines. This case scenario was artificially created as far as the times and amounts of intake, and the resulted activities in the thyroid and excreted urine are concerned. However real working conditions and monitoring programs were used as a basis for the simulation. The work involves labelling different organic compounds with ^{125}I. Chemical preparation is assumed to be done in a ventilated hood. Different risks of inhalation of radioactive iodine could be associated with different phases of the preparation. This kind of work is repeated several times in the year but not at regular time periods. In the given case the worker handled high levels of activity when

preparing ^{125}I labelled compounds and since the procedure was repeated many times in a year, routine monitoring of the worker is reasonable.

The main aim of this artificial case was to investigate and demonstrate the importance of the selection of the monitoring interval and its influence on the calculated intake and dose values. The given 30, 60 and 90 days monitoring intervals were chosen on the basis of the recommendations of ICRP Publication 54. Another additional aim was to investigate in a given case the differences in assessed dose when applying different monitoring methods, and if using two methods – namely thyroid and urine activity measurements – simultaneously, how this additional information can be used to improve the assessments of intake and committed dose.

When preparing the case scenario, several possible situations were assumed concerning the times and amounts of multiple intakes, and the times of monitoring. There were simulated situations when the intake occurred soon before or soon after the time of monitoring, but there were also monitoring intervals during which no intakes, or several intakes, were assumed to occur. The activity of ^{125}I intakes were also very different during the investigated period. For the intake pathway, the assumption of inhalation seemed to be obvious and for the sake of simplicity an AMAD of 1 μm was assumed. The chemical form was assumed to be iodide.

When generating the activities in the thyroid and in 24 hour urine samples at the time of monitoring, the contribution of the remaining activitydue to previous intakes was also considered. The computer code LUDEP was used for generating the data, assuming that the behaviour of our hypothetical person follows the recent respiratory tract and biokinetic models recommended by the ICRP. These generated data were provided to the participants without imposing randommeasurement uncertainties because it was supposed that there were enough influencing factors, parameters and assumptions which had to be the subject of personal judgement of the participants.

The dates of intakes and corresponding “true” values of intakes are given in Table 4.3.3.1.

Table 4.3.3.1 : True values and dates of intakes.

Date	02.12.95	22.12.95	08.02.96	04.05.96	22.06.96	20.09.96	12.10.96	18.11.96
Intake (kBq)	25	16	8	4	24	6	16	10

Summing up the intakes occurring in 1996, a value of 68 kBq is obtained. The reference values for committed effective dose resulting from a 68 kBq intake in the year 1996 is 360 μSv or 500 μSv assuming a dose coefficient of 5.3×10^{-9} Sv/Bq (ICRP Publ. 68, IAEA IBSS 1996) or 7.3×10^{-9} Sv/Bq (ICRP 78) respectively. As for the committed equivalent dose of the thyroid due to the intake in 1996, the reference values ranged from 6.8 mSv to 10 mSv depending on the source of data and on the way of calculation but it could be as high as 16.7 mSv when mixing the previous and recent ICRP recommendations.

Altogether 38 participants out of the 50 submitted results on case 3 and some of them provided more than one answer applying different possible approaches. In this latter case only one set of results belonging to the most preferred method has been included in the tables and figures using all information provided by the participants. If the participant provided data for the intake in the year of 1996 and for the corresponding dose values calculated from either the thyroid or urine activities (B tables) and derived the best estimate not from these values but by using different methods of calculation, then the tables may contain results based on different approaches.

Most of the participants assumed multiple single intakes in the evaluation of monitored data. Only five evaluations (ID 5, 22, 36, 37 and 47) assumes a series of continuous intakes occurring during the monitoring intervals. In this latter case, estimation of the dates of intake is not relevant. The great majority of participants, namely 17, assumed partly or exclusively repeated single intakes occurring at the mid-time between two monitoring dates. Consequently they provided as many dates as there were monitoring periods.

These participants disregarded the fact that there were monitoring intervals (in the case of the 30 and 60 day monitoring periods) during which no intake occurred and this could have been concluded from the two consecutive monitoring data. It may be that the case description was misunderstood by some participants. It indicated that the work was repeated several times in a month and that different phases of the work were connected with different risks of intake. It was not intended to give the impression that the intakes really occurred at the same frequency.

The best results for estimated dates of intakes in the case of the 30 day monitoring period were provided by those participants who used simultaneously both the thyroid and urine measurements. These two sources of information are suitable for this purpose since the thyroid activity is changing very slowly with time after the intake while the activity excreted in urine varies considerably, especially in the initial period after the intake. This approach was followed by 7 participants (ID = 3, 6, 15, 17, 19, 27 and 29) and 5 of them (ID= 3, 6, 15, 17, and 29) estimated most of the dates within ± 3 days. It should be mentioned that the interpretation of the intake occurring on 12.10.1996 caused difficulties to some participants because it took place very soon before the monitoring date of 16.10.1996.

Figures 4.3.3.1 a-c show the frequency distributions of the estimated dates of intake in the case of 30, 60 and 90 days monitoring intervals. The true dates are also indicated in the figures. It can be seen that most of the participants used the mid-point concept for all three monitoring intervals. However in Fig 4.3.3.1a there are also small maxima close to the true dates, corresponding to the successful use of the approach where thyroid and urine activity measurements were combined in the intake date estimation. The assumed intake values spread considerably depending on the method used. From those participants who submitted relevant data sets, several provided estimates of intake values based on thyroid monitoring and a 30 day monitoring interval which were quite close to the “true” ones (ID 3, 4, 6, 15, 27, 28, 29, 31, 34 and 46). Remarkably, those participants who estimated approximately correct times of intakes also provided estimates of intakes which were close to the “true” values. Most of them used simultaneous evaluations based on both thyroid and urine data. As it could be expected the intakes estimated by using urine monitoring data proved to be less reliable than those based on thyroid activity measurements especially in situations where the time of monitoring is close to the time of intake. The tables presented in Annex F3.2 give the submitted results, namely the total intake of ^{125}I that occurred in the year of 1996, the committed equivalent dose ($H_{th,96}$ (50)) to the thyroid due to this intake and the corresponding committed effective dose (E_{96} (50)). The estimated values of these three quantities derived from thyroid and urine monitoring data, as well as the best estimates, are shown in these tables for 30, 60 and 90 days monitoring intervals. The best estimates are also compiled in a separate table. The outlying results printed in shadowed boxes are not included in the mean values and in the corresponding standard deviations but they are considered when indicating the minimum and maximum values.

One can see from the tables, that most of the results from two participants (ID 36 and 40) are outlying from the given log-normal distribution considering the statistical criteria accepted for this document. One of these two participants assumed series of continuous intakes while the other assumed acute intake, but both overestimated the expected values. It has to be mentioned that the numerical data submitted by the participants are diverging very much from the point of view of number of significant figures used when filling in the tables, namely it varies from 1 to 6. When looking at the statistical evaluation of data given in Tables 4.3.3.2 a-c, one can draw the following conclusions.

Table 4.3.3.2: Summary results on ^{125}I intakes in 1996, the corresponding committed equivalent dose to the thyroid and the committed effective dose
a) 30 days monitoring interval

	Intake in 1996 [kBq]			$H_{th,96}(50)$ [mSv]			$E_{96}(50)$ [mSv]		
	T	U	Best	T	U	Best	T	U	Best
Geometric mean	76.6	114	73.2	10.0	17.6	10.2	0.428	0.694	0.441
Geometric standard deviation[1)]	1.52	2.01	1.43	1.61	2.03	1.54	1.53	2.05	1.53
Arithmetic mean	83.8	144	77.4	11.1	22.6	11.1	0.467	0.924	0.480
Arithmetic standard deviation	39.1	103	24.6	5.14	17.6	4.88	0.208	0.876	0.207
Minimum[2)]	15.5	4.94	21.8	3.2	4.8	3.2	0.16	0.24	0.16
Maximum[2)]	215.6	457.43	311.06	47.3	77.75	52.87	2.2	14	2.2
"True" value	68			6.8 - 10			0.36 - 0.50		

b.) 60 days monitoring interval

	Intake in 1996 [kBq]			$H_{th,96}(50)$ [mSv]			$E_{96}(50)$ [mSv]		
	T	U	Best	T	U	Best	T	U	Best
Geometric mean	56.4	72.4	54	8.49	12.4	7.78	0.341	0.512	0.354
Geometric standard deviation[1)]	1.45	2.34	1.49	1.38	2.05	1.3	1.36	2.16	1.59
Arithmetic mean	59.9	99.8	58.1	8.92	16.1	8.04	0.357	0.692	0.401
Arithmetic standard deviation	20.2	79.1	22.1	2.94	13.2	2.10	0.107	0.627	0.188
Minimum[2)]	19	9.74	23	2.3	3.9	2.3	0.12	0.15	0.12
Maximum[2)]	216.6	299.2	216.6	47.4	65.8	47.4	2.4	3.2	2.4
"True" value	68			6.8 – 10			0.36 - 0.50		

c.) 90 days monitoring interval

	Intake in 1996 [kBq]			$H_{th,96}(50)$ [mSv]			$E_{96}(50)$ [mSv]		
	T	U	Best	T	U	Best	T	U	Best
Geometric mean	40.5	40.4	37.5	5.91	6.34	5.70	0.258	0.26	0.245
Geometric standard deviation[1)]	1.45	1.78	1.68	1.56	1.59	1.60	1.50	1.61	1.58
Arithmetic mean	43.2	47.0	42.5	6.60	6.98	6.29	0.284	0.288	0.270
Arithmetic standard deviation	15.3	26.6	22.6	2.66	3.04	2.75	0.112	0.136	0.120
Minimum[2)]	10.3	3.7	11.4	1.9	2.18	1.8	0.08	0.09	0.09
Maximum[2)]	224.8	230.4	224.8	49.6	50.8	49.6	2.4	2.4	2.4
"True" value	68			6.8 - 10			0.36 - 0.50		

1) without dimension
2) including outliers

The mean values of results derived from urine activity measurement are much higher than those based on thyroid activity monitoring. The spread of results characterised by the standard deviations is also considerably higher for data estimated from urine monitoring. When comparing the corresponding results obtained for 30, 60 and 90 days monitoring intervals one can see that the mean values are considerably decreasing almost by a factor of 2 when increasing the monitoring interval from 30 to 90 days. Because in the evaluation of a series of routine monitoring data the shorter the monitoring interval the higher the accuracy, it seems obvious to compare the mean values obtained for 30 days monitoring interval to the “true” ones. It turned out that the mean values of the intake and dose estimates were found to be quite close to the ’true’ ones and the geometric means (GM) are closer than the arithmetic means (AM) to the ‘true’ values. Slight overestimation can also be observed which is more reassuring than the opposite. As can be seen in Annex F3 most of the participants used either commercial or self developed ‘in-house’ computer codes for the evaluation. One can not find any correlation between the submitted results and the computer code used because the results are much more influenced by the intake assumptions than by the software.

When trying to compare results based on intake assumption of series of continuous exposure with those estimated assuming repeated acute intakes it seems that the former approach provides higher intake values than the latter ones.

Not all submitted answers contained complete information about the models applied and their parameters used. In the Table F3.2.6 of Annex F3 the compilation of limited information provided by the participants is shown. However one can derive from the submitted data the value assumed for the tissue weighting factor for the thyroid and the value of the dose coefficient. It turned out that some of the results, based on the previous ICRP recommendations concerning the respiratory tract model and

systemic biokinetics, were calculated by using the tissue weighting factor and the dose coefficient from the new ICRP recommendations.

The Figure 4.3.3.2 illustrates the relationship between the committed effective dose and the committed equivalent dose to the thyroid from which one can see the distribution of results with respect to the assumed values of w_T of 0.03 and 0.05. In Figure 4.3.3.3 the spread of data related to the dose coefficients are shown. One can conclude from this data that most of the values are grouped around $5.3*10^{-9}$ and $6.5*10^{-9}$ Sv/Bq where the first value corresponds to that one given in ICRP 68. Table 4.3.3.3 gives a summary of the models, w_T and dose coefficients used in the evaluation of this case. When investigating the reasons of the spread of final intake and dose results one should take into account, besides the various intake assumptions, the value of the dose coefficient, value of w_T, and the model used in the evaluation.

Table 4.3.3.3: Models used by the participants

Model	Number of participants		
	Respiratory tract	Tissue weighting factors for thyroid	Dose coefficient
ICRP 30	19	12	
ICRP 66	13	23	
ICRP 68			18
Others		1	18
N.s.	6	2	2

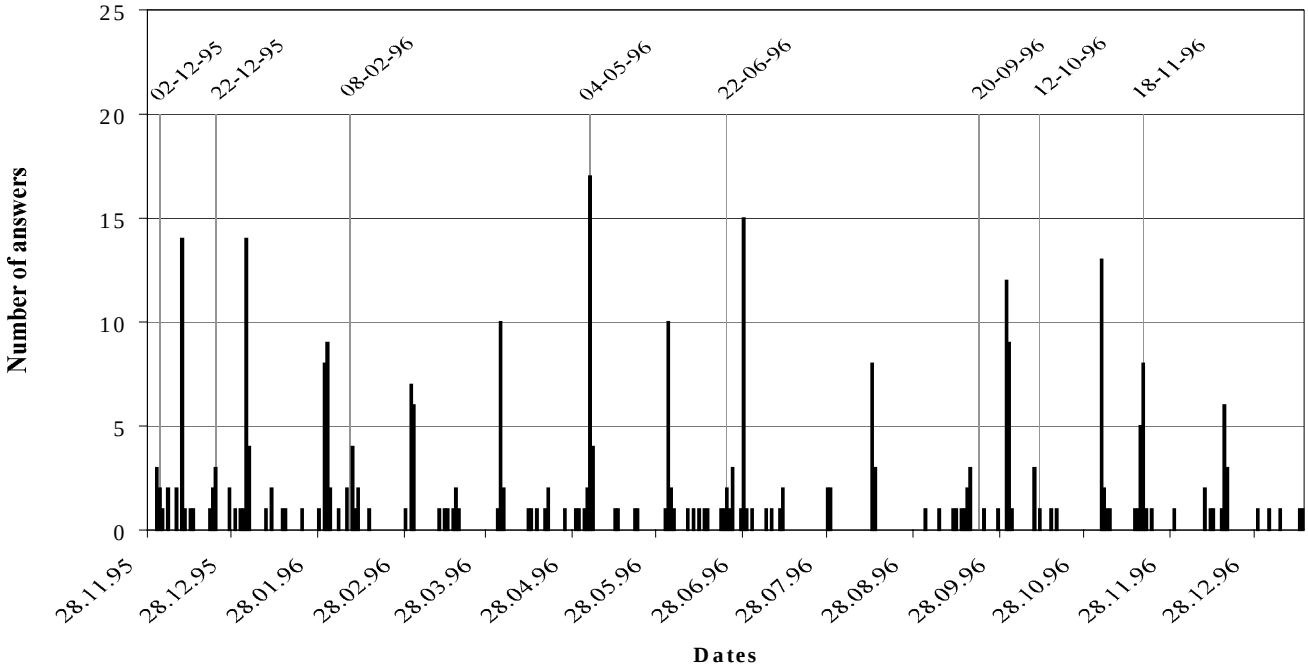


Fig. 4.3.3.1a: Frequency distribution of the estimated dates of intake in case of 30 days monitoring interval, indicating also the “true” dates of intake

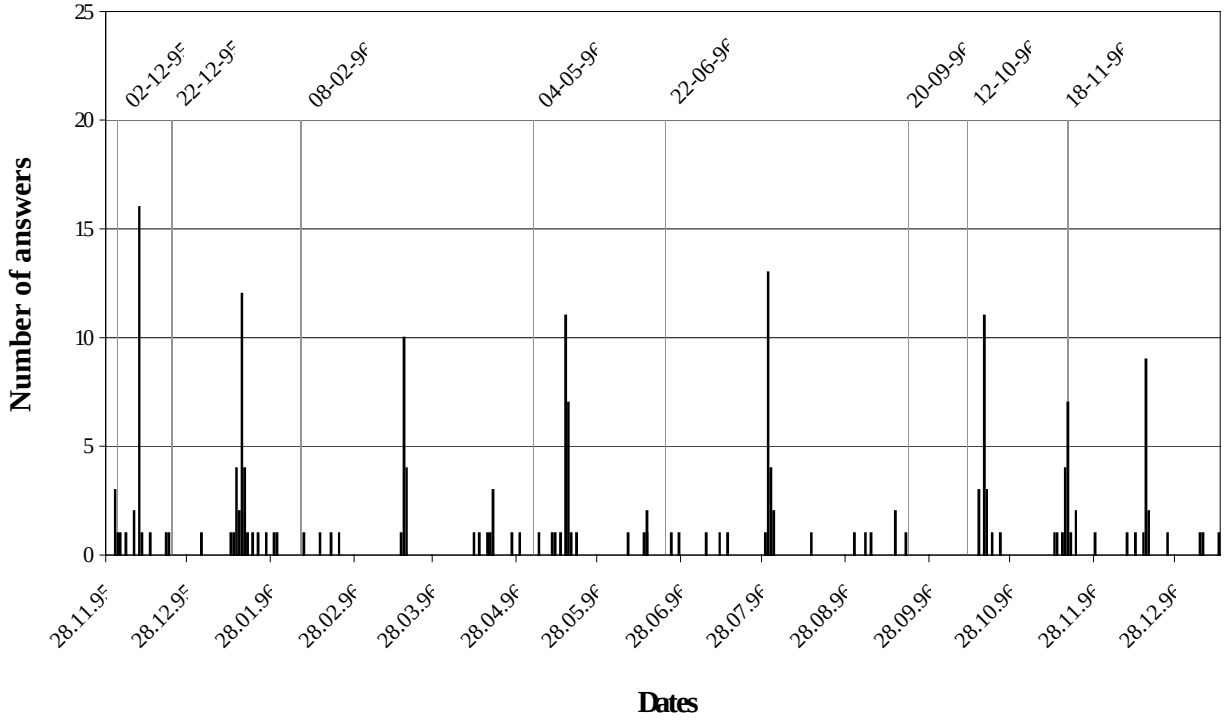


Fig. 4.3.3.1b: Frequency distribution of the estimated dates of intake in case of 60 days monitoring interval, indicating also the “true” dates of intake

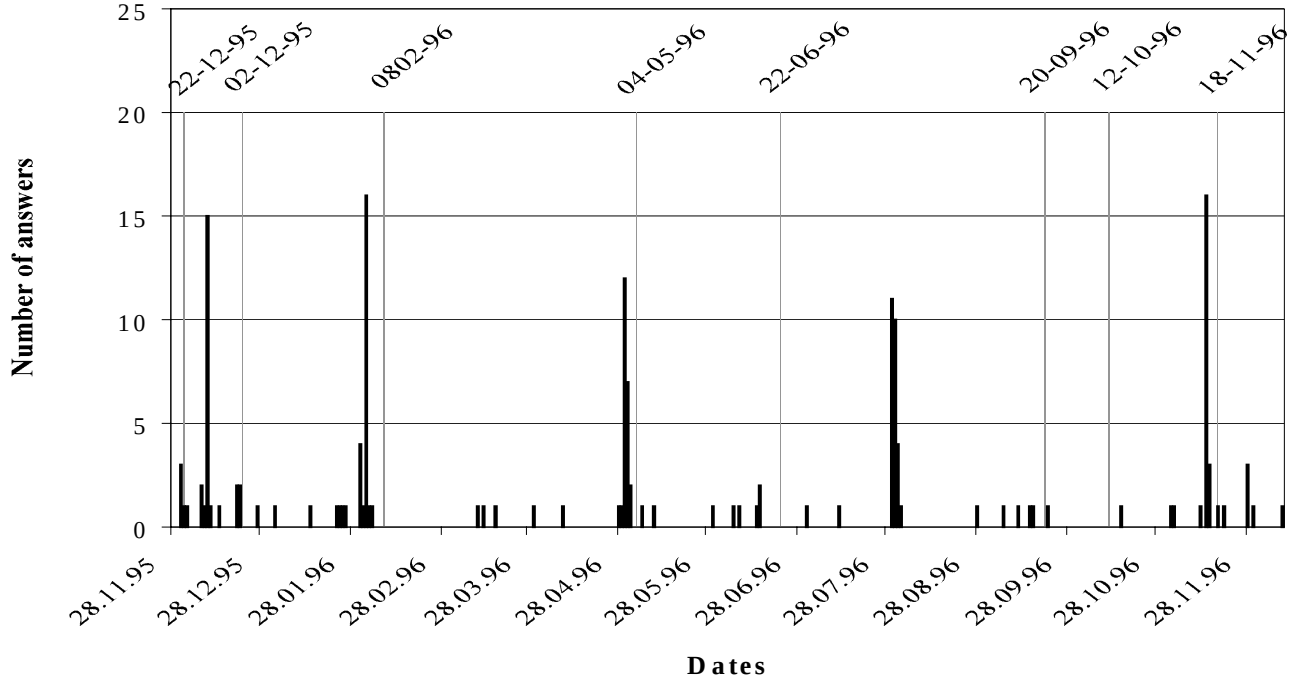


Fig. 4.3.3.1c: Frequency distribution of the estimated dates of intake in case of 90 days monitoring interval, indicating also the “true” dates of intake

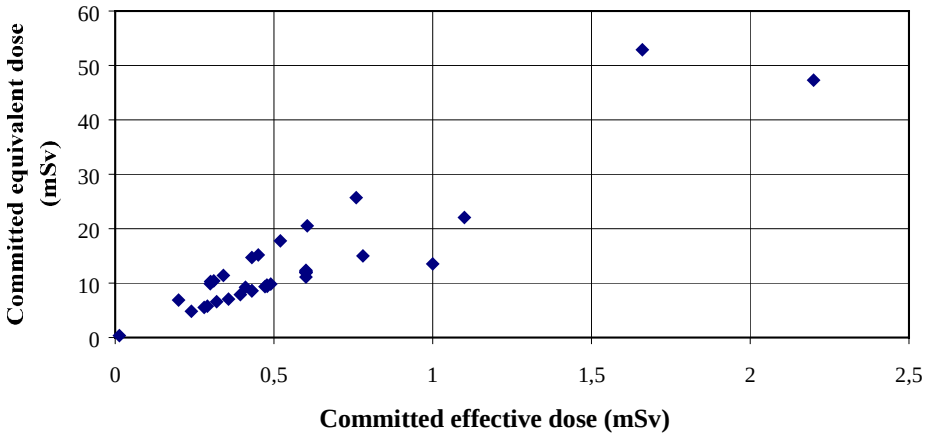


Fig. 4.3.3.2: Committed equivalent dose to the thyroid versus committed effective dose

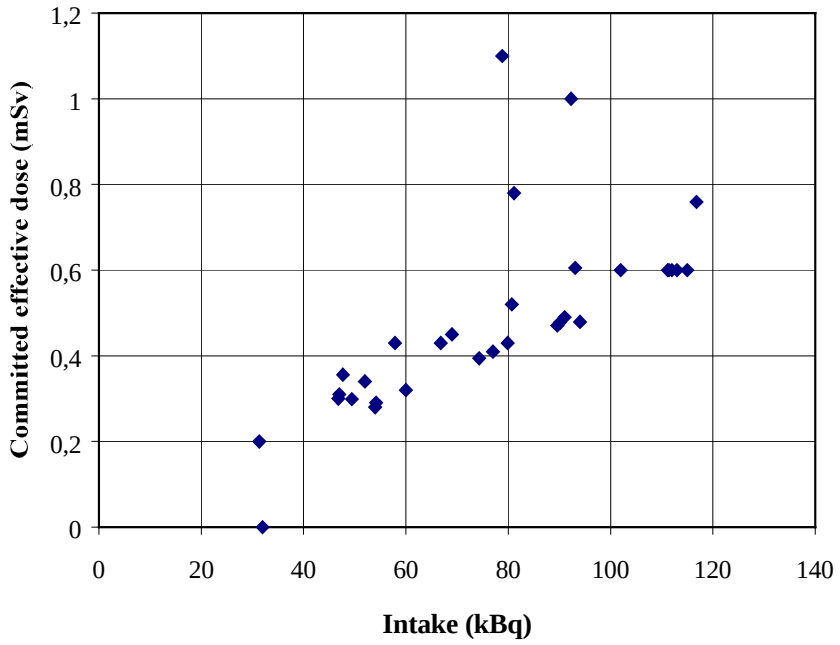


Fig. 4.3.3.3: Committed effective dose versus intake in 1996 based on best estimates for 30 days monitoring interval

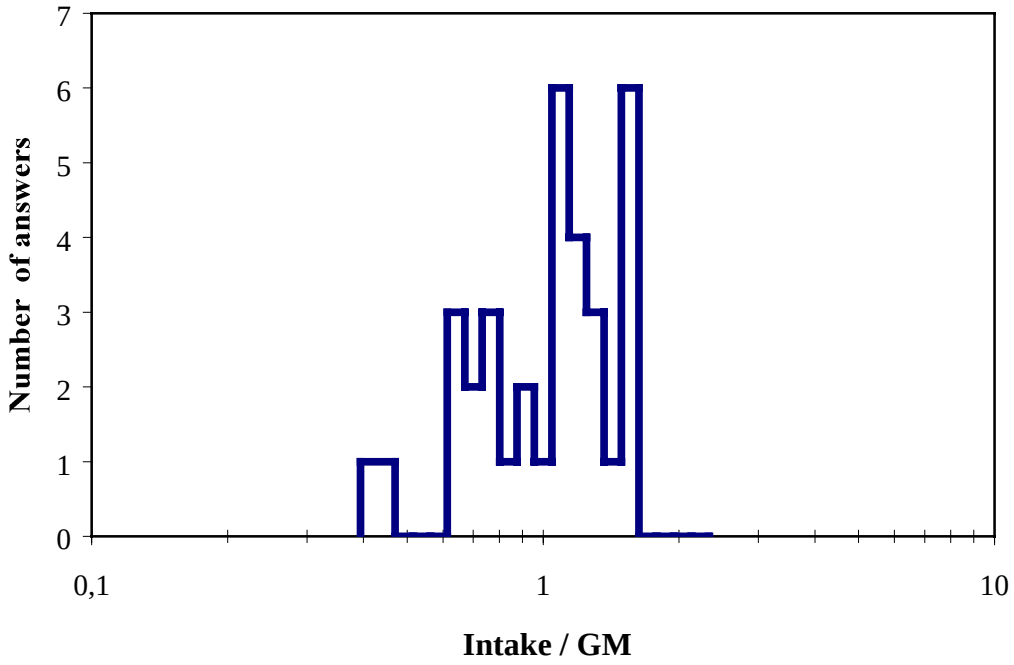


Fig. 4.3.3.4: Frequency distribution of the results based on 30 days monitoring interval: Best estimates of intake normalised to geometric mean (GM = 73.2 kBq; GSD = 1.43; 98.9 % C.I. = 29.9 – 179 kBq)

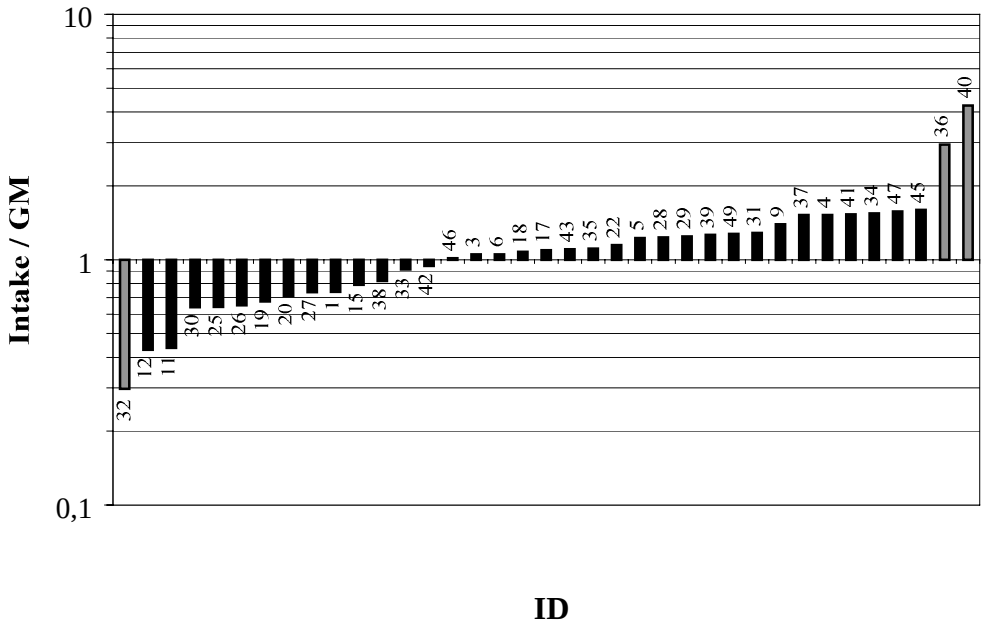


Fig. 4.3.3.5: Results of the individual participants (ID): Best estimates of intake based on 30 days monitoring interval normalised to geometric mean (GM = 73.2 kBq; GSD = 1.43; 98.9 % C.I. = 29.9 – 179 kBq)

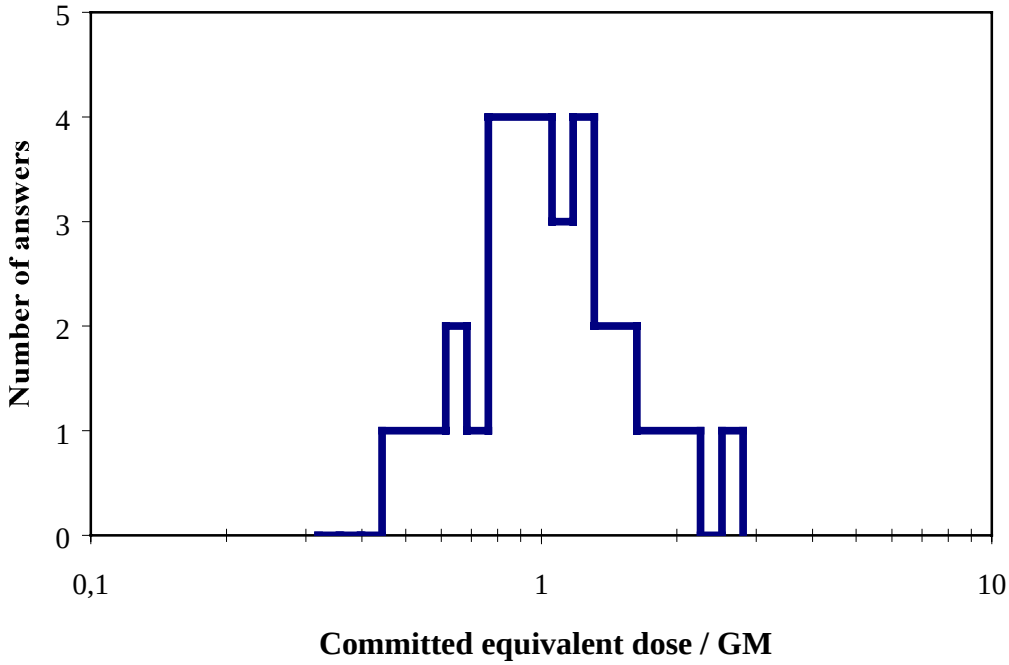


Fig. 4.3.3.6: Frequency distribution of the results based on 30 days monitoring interval: Best estimates of committed equivalent dose to the thyroid normalised to geometric mean (GM = 10.2 mSv; GSD = 1.54; 98.9 % C.I. = 3.47 – 30 mSv)

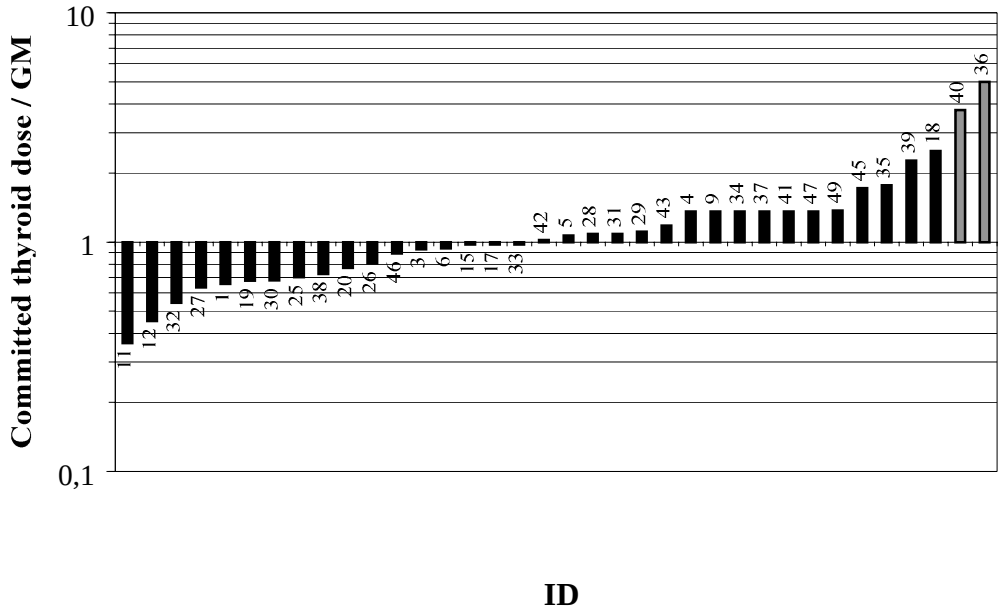


Fig. 4.3.3.7: Results of the individual participants (ID): Best estimates of committed equivalent dose to the thyroid based on 30 days monitoring interval normalised to geometric mean (GM = 10.2 mSv; GSD = 1.54; 98.9 % C.I. = 3.47 – 30 mSv)

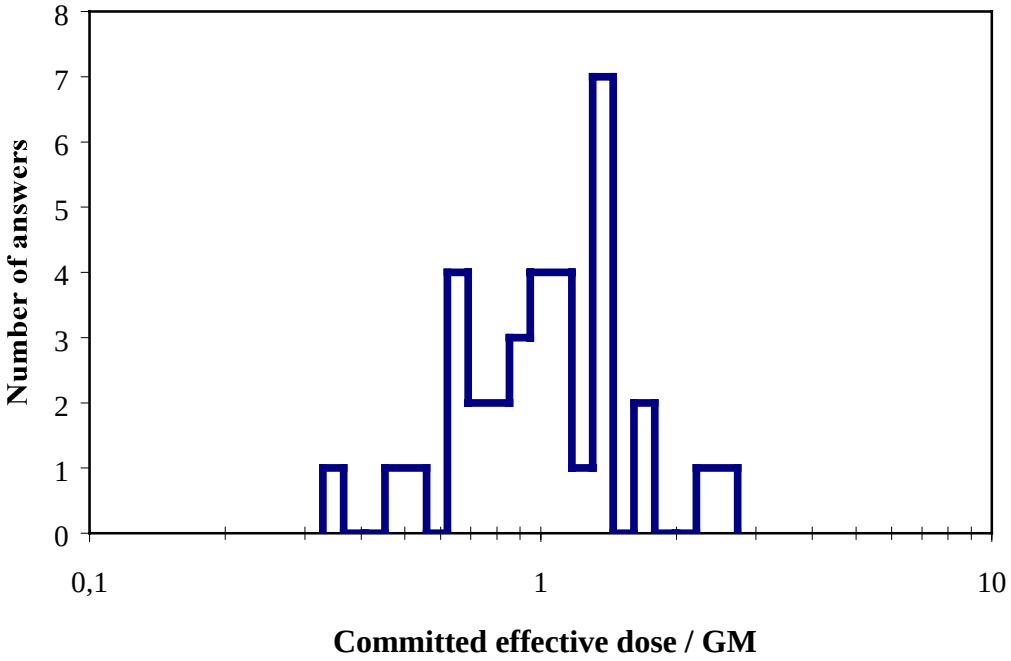


Fig. 4.3.3.8: Frequency distribution of the results based on 30 days monitoring interval: Best estimates of committed effective dose normalised to geometric mean ((GM = 0.441 mSv; GSD = 1.53; 98.9 % C.I. = 0.152 – 1.28 mSv)

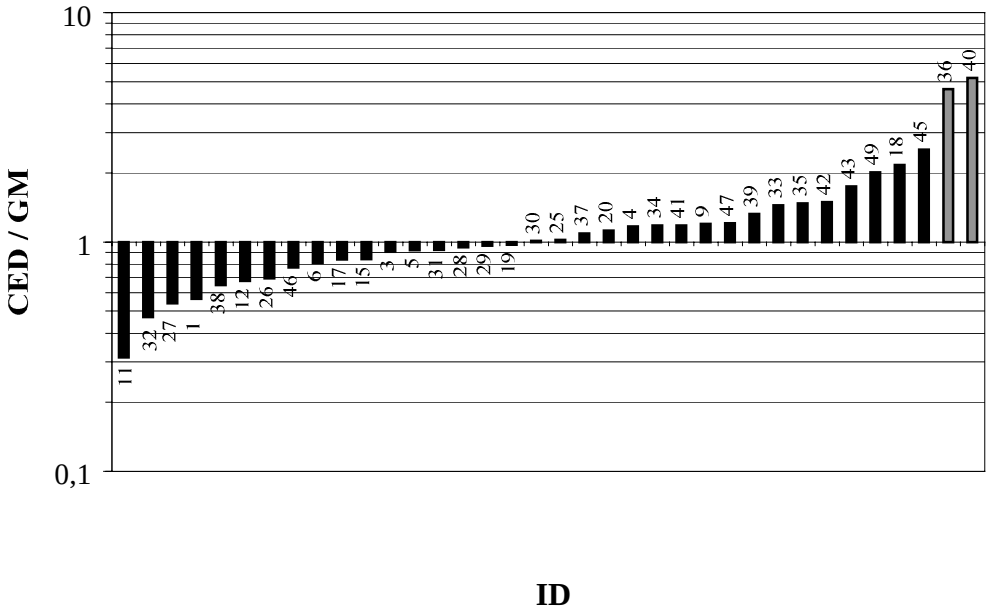


Fig. 4.3.3.9: Results of the individual participants (ID): Best estimates of committed effective dose based on 30 days monitoring interval normalised to geometric mean (GM = 0.441 mSv; GSD = 1.53; 98.9 % C.I. = 0.152 – 1.28 mSv)

4.3.4 Continuous intake of ^{137}Cs

This intake scenario describes the behaviour of the internal contamination of one person living in the Po valley (Italy) following the spread of fission products in atmosphere and subsequently in the environmental and food chains, after the Chernobyl accident. As a tracer of the mix of the radionuclides emitted during the accident, ^{137}Cs is followed by means of whole body counter measurements. The data reported in the case scenario belongs to a subject living in the city of Bologna who is taken as a sample of the adult male population (about 20 people were systematically measured by WBC).

WBC measurements were performed on a regular basis; at first approximately monthly and later approximately every 2 months. In August some measurements were missed due to the unavailability of the subject. The measurements are of internal body activity. Repeated calibrations with a BOMAB type phantom ensured measurement precision. The overall period spans from the first month after the accident to approximately 880 days later. In Fig. 4.3.4.1 it is possible to find two patterns in the internal body burden behaviour. The first, shows an increase due to ingestion of foodstuffs contaminated with caesium. In the period of May to July 1987 a quasi-steady state condition was reached and then a second phase of decreasing activity begins. In this phase biological clearance from the body is the main phenomenon which takes place as the daily intake progressively decreases.

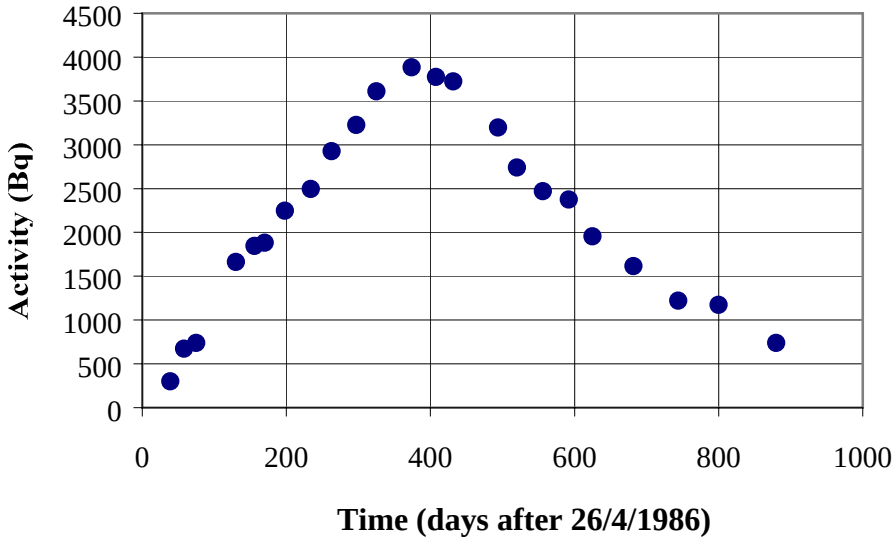


Fig. 4.3.4.1: Time dependence of measured whole body ^{137}Cs activity.

The participants were asked to make their own best evaluation of the total intake (I) from the accident until the end of the monitoring period, the effective dose received by the subject in 1986 (E86) and 1987 (E87) and the committed effective dose (CED) due to the total intake previously evaluated. The effective dose received in the first two years may be evaluated by assessing the intake or directly from the whole body content and the participants were requested to clearly indicate the method used. In one case (ID 48) the participant indicated that values given for 1986 and 1987 are related to committed effective dose due to the intake in the respective year.

The majority of participants (43 out of 50) submitted results for this case (from 0.5 to 4.5 pages): 37 gave complete answers for all 4 parameters; one participant (ID 49) gave answers only for E86, E87 and CED; 2 participants gave answers only for E86 and E87 (ID 26 and 43) and 3 participants (ID 24, 31 and 40) gave answers only for I and CED. In total there are 40 evaluations of I,

40 evaluations of E86 and E87 and 41 evaluations of CED. Of the 40 answers related to E86 and E87, 27 evaluations are via intake and 13 directly from body burden.

A check with the above mentioned procedure was carried out to identify values not related to the general distribution. The procedure was applied to the whole set of data for I and CED and separately for the 4 subsets relating to the evaluation of effective doses in 1986 and 1987 considering the evaluation both via intake and directly. The results of this evaluation are reported in Table 4.3.4.1

Table 4.3.4.1 : Identification of outliers.

	Intake	E86 Via intake	E86 Directly	E87 Via intake	E87 Directly	CED
Number of participants [1)]	40	23	17	23	17	41
Number of identified outliers	4	None	1	None	2	6
ID of outliers	32,39,40,42	None	10	None	17,32	14,24,28,32 39,40

1) including outliers

Many participants provided results obtained in different ways (especially for the evaluation of E86 and E87). As only one answer can be considered for intercomparison purposes participants were requested to indicate which result was to be used. Personal data for the subject are not far from that of Reference Man (80 instead of 70 kg weight) so only two participants (ID 13 and 49) have used parameters related to 80 kg mass. Practically all the participants consider the pathway of intake as ingestion: only 2 participants (ID 9 and 32) indicate inhalation as the intake pathway. Some answers are not detailed enough to understand the way in which the participant have handled the case but in the majority of cases the information provided is enough to follow the approach.Several intake patterns were assumed: constant chronic ingestion during a unique period of time, repeated ingestion by means of single intakes in the mid point of the monitoring period taking into account intakes from the earliest periods, different continuous constant chronic intakes (from 2 (Part. ID 2) to 5 in the whole monitoring period (Part. ID 5)), large number of acute intakes (e.g. 1 intake every 5 days (Part. ID 33)), end of the intake 374 (Part. ID 6) or 425 (Part. ID 46, 13) days after the accident, trapezium-rule with extrapolation after 22/9/88 for evaluation of CED (Part. ID 9, 13, 29, 49), in some cases the way of the extrapolation for the time after the monitoring period is not specified. This caesium case, being simple, can be expected to give values very close to each other. The results of the statistical evaluations on data-sets without considering outliers is reported in Table 4.3.4.2. As can be seen the range of intake is 4.3-53.37 kBq (ratio max/min = 12.4). For the CED the range is 0.028 – 1.075 mSv (ratio max/min = 38.4). For the 40 participants for which a dose coefficient can be calculated the values are: range $6.51\ 10^{-9}$ - $1.80\ 10^{-7}$ (ratio max/min = 27.6); GM = $1.44\ 10^{-8}$ Sv/Bq, GSD= 1.61.

As can be seen the spread of data in the evaluation of E86 and E87 is greater in the case of evaluation of intake (GSD about 1.3) than in the case of evaluation made directly (GSD about 1.1): Also the ratio max/min was greater via intake (about 3) than directly (about 2). This can be explained as there is no necessity for introducing assumptions about the pattern of intake in the evaluation of dose made directly on whole body burden data. So data related to direct evaluation of intake are affected by lower variability. Many models were used by participants for the evaluation of intake and dose coefficients. For the calculation of retention ICRP 30, 54, 67, NUREG CR 4884 have been cited. For the dose coefficients several models or tabulations are presented: ICRP 56, 68, IAEA BSS, ICRP 67, 69 (only ID 44), 71(related to inhalation pathway, ID 32).

Table 4.3.4.2 : Statistical evaluations of the results

	Intake (kBq)	E86 Via intake (mSv)	E86 Directly (mSv)	E87 Via intake (mSv)	E87 Directly (mSv)	CED (mSv)
N. [1)]	36	23	16	23	15	35
GM	13.91	0.039	0.033	0.110	0.111	0.198
GSD [2)]	1.26	1.39	1.18	1.26	1.08	1.15
AM	14.26	0.041	0.034	0.113	0.112	0.200
ASD	3.18	0.015	0.006	0.026	0.009	0.029
Minimum[3)]	4.3	0.021	0.025	0.065	0.072	0.028
Maximum[3)]	53.37	0.078	0.063	0.168	0.128	1.075

1) without outliers
2) without dimension
3) including outliers

Table 4.3.4.3 : Comparison of results between CINDY and LUDEP users

	LUDEP users		CINDY users	
	Intake (kBq)	CED (mSv)	Intake (kBq)	CED (mSv)
N	8	6	6	6
GM	13.0	0.189	13.7	0.205
GSD	1.38	1.13	1.32	1.11
Min	8	0.16	8.1	0.180
Max	23.3	0.232	17.2	0.230

A comparison between old and new models can be done by selecting participants using the CINDY and LUDEP computer codes. Results of this comparison excluding outliers are reported in Table 4.3.4.3. From the results it can be seen that the use of the same model does not give uniform results, especially for LUDEP users.

The table shows there are no significant differences between use of the old and new models. The majority of participants used the default ICRP 30, 67 caesium parameters in particular the long biological half time of 110 d. Only 3 participants (ID 4, 6 and 46) used 200 d as the long term half life due to fitting procedures. The results of these participants seem to be lower (about a factor of 2) for intake and similarly for CED when compared with the others. This means a dose coefficient twice that used by the majority of participants. The majority of participants used all of the data; only participants ID 6, 13, 46 have not used data after 374 or 425 d after the accident. Errors on the evaluations are only

reported by participant ID 15 (about 33% for each value) and 32 (only for intake 57%). It is not possible to understand how these values are derived and at what confidence interval they refer.

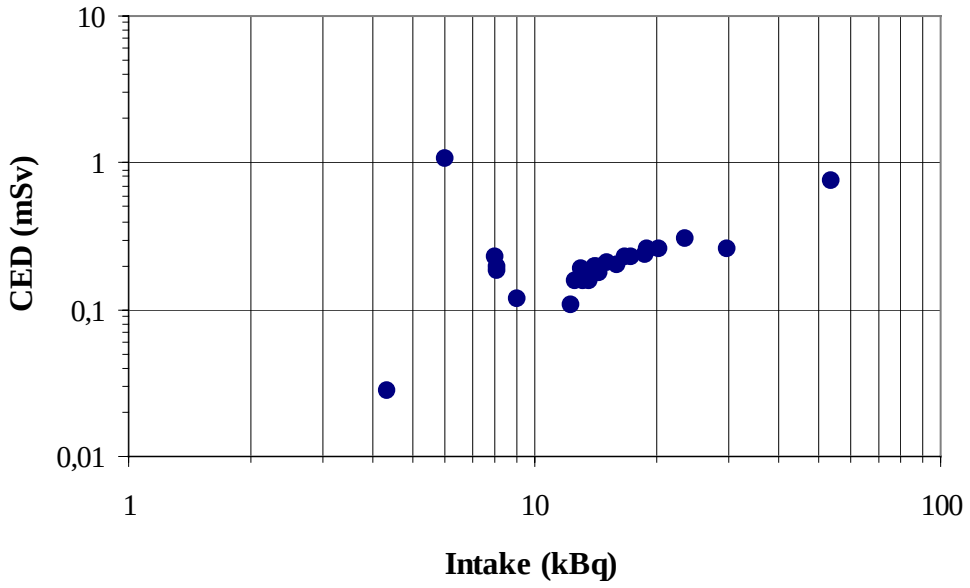


Fig. 4.3.4.2: Committed effective dose versus intake

In Fig. 4.3.4.2 the scatter plot of CED versus intake values is reported. The 4 points at approximately 4.5, 6, 30 and 55 kBq are all considered as outliers for intake. Two other points having ordinates at approximately = 0.1 mSv and abscissa 9 and 12 kBq are also identified as outliers for dose. The 3 values having an intake of 8 kBq and a CED value approximately = 0.2 are all related to models using Tb for the log term component equal to 200 d. Considering the remaining values (29 evaluations, main cluster of data) it is possible to fit the data by means of a linear regression which gives a statistical passage through the origin and a coefficient of (1.33 ± 0.08). 10^{-8} Sv/Bq with correlation coefficient of 0.956. This means that even if using different models the dose coefficient does not differ in a significant way for the main cluster of data.

This case appeared to be rather simple,nevertheless considering all of the data the ratio of the highest to the lowest estimate of CED is about 40 (1.075/0.028) with no apparent gross error and without correlation to the intake estimate. The spread of data is principally due to the pattern of intake used (series of acute intake, continuous intake, constant chronic intake within different intervals, etc). The overall variability remains always low (GSD values are always below 1.7); results for E86 and E87 evaluated directly from body burden show even smaller variability than those evaluated via intake. The differences in dose results are due to differences in data interpretation, methodologies and the resulting different evaluation of intake. No correlation can be found about the use of specific computer codes and the results: mean values of the parameters for CINDY and LUDEP users do not permit the evaluation of differences between the new and old models. In spite of this the main cluster of data refer to a mean dose coefficient that does not differ in a significant way between participants. The main cluster of data ranges from 12.5 to 20.12 kBq for intake from 0.16 to 0.266 mSv for committed effective dose.

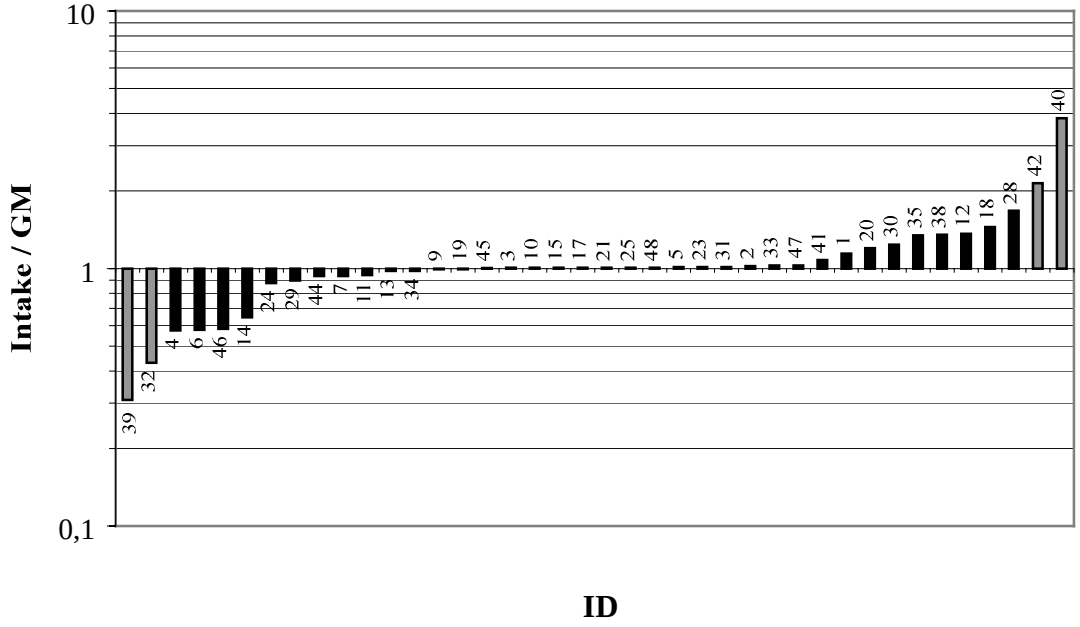


Fig. 4.3.4.3 : Results of the individual participants (ID): Intake normalised to the geometric mean (GM = 13.91kBq ; GSD= 1.26; 98.8 % C.I. = 7.81 – 24.79 kBq)

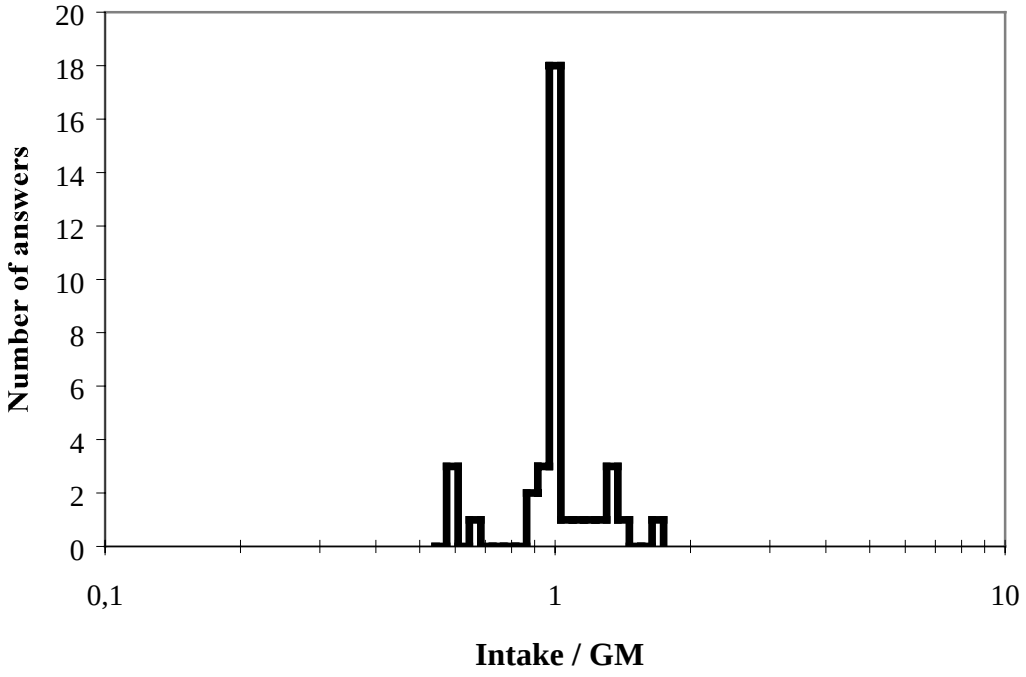


Fig. 4.3.4.4 : Frequency distribution of the results: Intake normalised to the geometric mean (GM = 13.91kBq ; GSD= 1.26; 98.8 C.I. = 7.81 – 24.79 kBq)

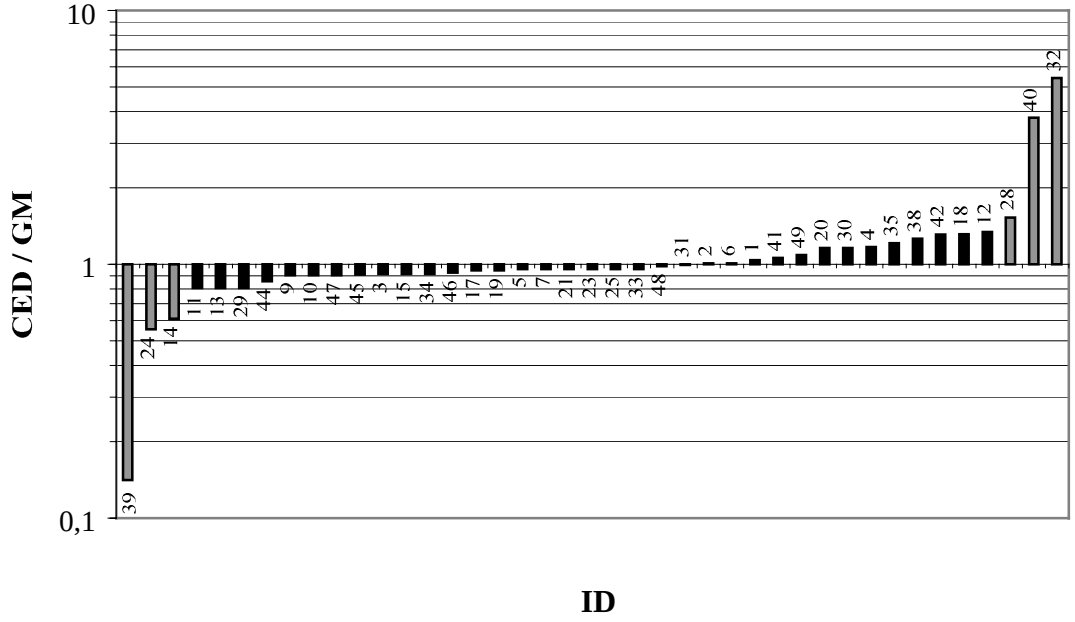


Fig. 4.3.4.5 : Results of the individual participants (ID): Committed effective dose normalised to the geometric mean (GM = 0.198 mSv ; GSD= 1.15; 98.8 % C.I. = 0.140 – 0.281 mSv)

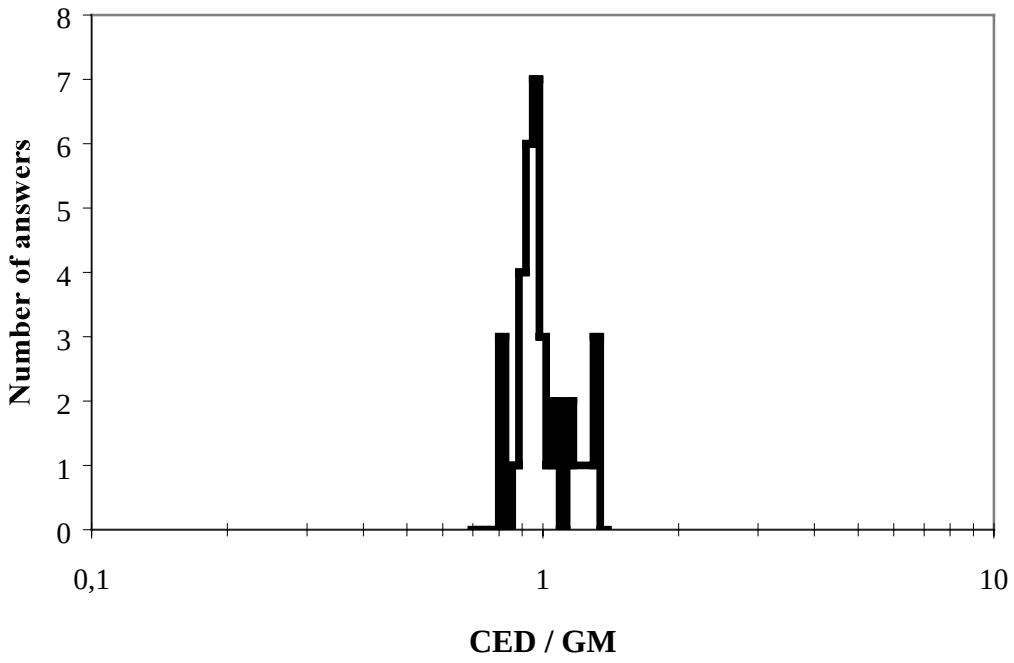


Fig. 4.3.4.6 : Frequency distribution of the results: Committed effective dose normalised to the geometric mean (GM = 0.198 mSv ; GSD= 1.15; 98.8 % C.I. = 0.140 – 0.281 mSv)

4.3.5 Enhanced intake of natural activity

This case scenario is related to the environmental measurements performed in a factory which produces electro-fused refractory blocks using zircon sands. The factory, located in the northern part of Italy, has been investigated by the "National Group for Studying Radiological Implications in the use of Zircon Sand" which reported the results of a measurement campaign in the factory in the "The Science of the Total Environment" Vol. 45, (1985) pp. 135 – 142. The case scenario involves non-radiation workers in a real case. The scope is to carry out a dose evaluation using measurements of the main aerosol parameters performed by means of three kind of instruments: total filter, dichotomous sampler and cascade impactor.

The participants are asked to make an evaluation of the possible increase of effective dose due to the inhalation of such materials during 1 year of continuous intake. Aerodynamic mass distribution was evaluated and two main modes of the aerosol resulted: one centred on 0.27 μm aerodynamic diameter, the other around 10.3 μm. Measurements of activity concentration in the used sand of the radionuclides belonging to the natural families and to ^{210}Po were also provided as well as total alpha activity concentration in air connected to ^{210}Po alone and to natural radioisotopes as a whole. The fractions of overall activity pertaining to each aerosol mode was given too. In the case description it states that the modal parameters describing the particle distribution in terms of activity are identical to those describing the particle distribution in terms of mass for both the measured aerosol modes. It has been also specified that the duration of exposure is 8 h/d for 250 d/y at a standard breathing rate of 1.2 m^3/h for a non-smoker subject.

The participants are requested to evaluate annual intake of ^{210}Po, and of the parents radionuclides of the natural families : ^{238}U, ^{235}U, ^{232}Th. They are also asked for the evaluation of committed effective dose (E(50)) due to 1 year of exposure. For the natural families the secular equilibrium of each radionuclide in the respective chain has been suggested. Twenty participants out of 50 submitted results for this case scenario, so this case has the smallest number of answers (40%) of this intercomparison exercise. The length of the answers varied from ½ to 5 pages; generally it can be easily understood how the participants have made the evaluations. In rare cases (especially for smallest answers) some problems arose. In the 8 sets related both to intake and to committed effective dose values, by means of a standard procedure some values not pertaining to the general distribution were identified. Namely for ^{238}U and ^{232}Th intake participant ID 1 and 5 have been identified; for ^{235}U intake participant ID 1 has been identified. For ^{210}Po committed effective dose participant ID 33 has been identified as not pertaining to the general distribution. The general statistical results are presented in the Tables 4.3.5.1 and 4.3.5.2, for intake and E(50), respectively.

Table 4.3.5.1 : General statistics related to intake data

	Intake			
	^{210}Po	^{238}U	^{235}U	^{232}Th
Number of answers	20	18	19	18
GM (Bq)	1027	6.98	0.35	1.72
GSD	1.01	1.41	1.43	1.39
Min (Bq)	1000	5.5	0.24	1.36
Max (Bq)	1038	50.8	2.15	10.83

Table 4.3.5.2 : General statistics related to committed effective dose data

	Committed effective dose			
	^{210}Po	^{238}U+daug.	^{235}U+daug.	^{232}Th+daug.
Number of answers	19	20	20	20
GM(μSv)	3180	355	13.7	157.1
GSD	1.25	2.31	2.62	2.80
min (μSv)	910	77	1.7	17.1
max (μSv)	4310	2418	117	775

Some participants (ID 25 and 30) indicate that their evaluation refers to committed effective dose equivalent (considering weighting factors from ICRP 26) and not to committed effective dose; however in the statistical evaluations these values have been pooled with the others considering them as best estimate of E(50). Ratios Max/Min for intake, considering also outliers, span from 1.04 for ^{210}Po, to 9.2 for ^{238}U, 9 for ^{235}U and to 8 for ^{232}Th. In general it can be indicated that the spread is limited : the ratios max/min are less than 5. Ratios Max/Min for E(50) span from 4.7 for ^{210}Po, to 31 for U^{238}+daughters, 69 for U^{235}+daughters and to 45 for Th^{232}+daughters. At maximum a factor of 70 has been found for the ratios max/min for E(50).

The participants used a unique pathway: inhalation. All modalities of exposure chronic exposures or repeated intake during 250 d have been indicated. All the participants evaluated the intake of ^{210}Po multiplying the measured alpha concentration in air (that numerically is equal to the activity concentration) by 2400 that represents the total amount of volume of air inhaled during 1 year, expressed in cubic metre. Only rounding figures determine differences in the provided results. Instead, three ways of evaluating the yearly intake of natural families parents have been followed. All the participants used the total volume of inhaled air in 1 year (2400 m^3) and an estimate of activity concentration derived in different ways.

1. Participant IDs 25, 30, 39 and 46 evaluated the intake using the provided activity concentration in the sand and the aerosuspended mass concentration derived as the ratio of the total alpha concentration measured by the filter (0.024 Bq/m^3) by the total activity concentration in the sand (sum of the radionuclides indicated, 12635 Bq/kg). This results in a concentration of 1.9 mg/m^3 that is more than twice the measured mass concentration (0.84 mg/m^3) so values of intake are roughly twice the values of the other participants. (Typical values of yearly intake are 13, 0.6, 3 Bq respectively for ^{238}U, ^{235}U, ^{232}Th.)

2. Participant IDs 4, 6, 7,14, 18, 20, 29, 33, 42, 48, 49 evaluated the intake using the activity concentration in the sand and the measured mass concentration (0.84 mg/m^3). They don't use data of the total alpha concentration from the filter.(Typical values of intake are 5.7, 0.25, 1.36 Bq respectively for ^{238}U, ^{235}U, ^{232}Th)

3. Participant IDs 17, 21 and 34, used the total alpha activity concentration in the filter (0.024 Bq/m^3) as related to all radionuclides of the three families and the alpha fractions pertaining to each parent of the natural chains derived from the activity concentration of the zircon sand and the specific alpha emission of each chain considered in secular equilibrium (approximately 7 alphas for ^{238}U chain, 7 alphas for ^{235}U chain and 6 alphas for ^{232}Th chain). (Typical values of intake are 6.6, 0.3, 1.6 Bq respectively for ^{238}U, ^{235}U, ^{232}Th).

The spread of data determined by these methods is not as large as all data sets present GSD less than 1.5. In relation to the possibility to take into account the secular equilibrium between all the daughters of the natural families some remarks have been presented. Participant ID 5 indicates that he has considered that ^{222}Rn leaves the body and so he does not take into account the contribution of the lower part of the ^{238}U chain. The intake of the ^{238}U is thus resulted higher than the rest of other participants and it has been identified as not pertaining to the general distribution of the other data. Participant ID 29 indicates that the assumption of insignificant release of radon is unrealistic but for intercomparison purposes daughter products are considered in the human body and in the sand as well.

If data were available, the values of dose coefficient related to the different modes of aerosol have been compared. Table 4.3.5.3 shows the dose coefficient values for the parent nuclides.

Table 4.3.5.3: Values of dose coefficient for the parent nuclides (maximum values for any nuclide underlined, minimum values in italics)

Part. ID	Dose coefficient (Sv/Bq)							
	^{210}Po 1st mode	^{210}Po 2nd mode	^{238}U + d. 1st mode	^{238}U+ d. 2nd mode	^{235}U+ d. 1st mode	^{235}U+ d. 2nd mode	^{232}Th+ d. 1st mode	^{232}Th+ d. 2nd mode
4	5,050E-06	1,690E-06	1,080E-04	3,840E-05	1,070E-04	3,890E-05	1,320E-04	4,080E-05
5	3,836E-06	1,096E-06	*2,137E-05*	6,849E-06	3,890E-05	1,507E-05	1,397E-04	4,274E-05
14	3,752E-06	*1,047E-06*	1,086E-04	3,844E-05	1,075E-04	3,887E-05	1,319E-04	4,517E-05
17	3,752E-06	*1,047E-06*	1,034E-04	3,678E-05	1,074E-04	3,886E-05	1,318E-04	4,082E-05
34	4,104E-06	1,049E-06	1,151E-04	3,705E-05	1,197E-04	3,953E-05	1,443E-04	4,109E-05
39	4,758E-06	1,603E-06	1,057E-04	3,592E-05	*2,083E-05*	*3,600E-06*	*1,283E-05*	*3,760E-06*
46	4,758E-06	1,597E-06	1,018E-04	3,443E-05	1,048E-04	3,657E-05	1,280E-04	3,743E-05
49	*3,624E-06*	1,188E-06	5,160E-05	*5,160E-06*	7,180E-04	7,200E-05	5,788E-04	5,677E-04

All of the above participants used LUDEP 2.04 or 2.05 computer code (with ICRP 30 models for the systemic phase) for calculating dose coefficients by means of the case scenario parameters, except participant ID 5 who used LUDEP 2.75 (and ICRP 67 and 69 for the systemic phase) and participant ID 49 who used ICRP 30 making AMAD corrections for 0.3 and 10 μm by means of the suggested methodology. As can be seen in Table 4.3.5.3 the values related to ^{210}Po for both modes are close each other. (factor 1.4-1.6 for the ratio max/min). For the natural chains of radionuclides dose coefficients differ mainly because the participant takes or does not take into account the dose coming from the progeny. So, for instance the ^{238}U + daughters coefficient, participant ID 5 does not consider the radionuclides after ^{222}Rn, resulting in an order of magnitude less than the others. Not considering participants 5 and 49, the dose coefficients lie for ^{238}U near $1 \cdot 10^{-4}$ – $1.2 \cdot 10^{-4}$ Sv/Bq for mode 1, and $3.4 \cdot 10^{-5}$ – $3.8 \cdot 10^{-5}$ Sv/Bq for mode 2. For ^{235}U + daughters the maximum values are those of participant ID 49 that uses ICRP 30 and the minimum ones are those for participant ID 39 that uses ICRP 66 respiratory tract in LUDEP 2.04, perhaps not considering progeny. Also participant ID 5 gives dose coefficients roughly 2.7 times lower than the others. Not considering these participants the

dose coefficients lie for ^{235}U near $1 \cdot 10^{-4} - 1.2 \cdot 10^{-4}$ Sv/Bq for mode 1, and $3.7 \cdot 10^{-5} - 4.0 \cdot 10^{-5}$ Sv/Bq for mode 2. For ^{232}Th + daughters, as for the case of ^{235}U, the maximum values are those of participant ID 49 and the minimum ones are those for participant ID 39. Not considering these participant IDs the dose coefficients lie near $1.3 \cdot 10^{-4} - 1.4 \cdot 10^{-4}$ Sv/Bq for mode 1, and range from $3.7 \cdot 10^{-5}$ to $4.5 \cdot 10^{-5}$ Sv/Bq for mode 2. The spread of dose coefficients data is thus mainly determined by assumptions related to the equilibrium of radionuclides.

From this table comparing participant ID 5 with the others LUDEP users it can be stated that the use for the systemic phase of ICRP 67 and 69 models in LUDEP, instead of ICRP 30, does not affect dose coefficients for ^{210}Po and for the Th family. It is not possible evaluate such effect on ^{238}U as participant ID 5 does not assume the secular equilibrium of all radionuclides as it is done by the other LUDEP users. For ^{235}U it seems that dose coefficients are roughly 2.7 times lower than those evaluated by means of commercial LUDEP. The majority of participants use LUDEP in several versions for calculating dose coefficients, however the use of the same code does not imply that the results are close each other. A comparison of E(50) mean values between LUDEP and Non-LUDEP users indicate a lower spread of data for the LUDEP users and higher GM values except the case of ^{232}Th+daughters.

Table 4.3.5.4: Comparison of the results in terms of E(50) of LUDEP and non-LUDEP users

	E(50)							
	^{210}Po		^{238}U+daugh.		^{235}U+daugh.		^{232}Th+daugh.	
	LUDEP	Non-LUDEP	LUDEP	Non-LUDEP	LUDEP	Non-LUDEP	LUDEP	Non-LUDEP
Number of answers	12	8	12	8	12	8	12	8
GM (μSv)	3480	2376	452	248	16.4	10.3	110	268
GSD	1.19	1.55	1.81	2.87	2.19	3.28	2.45	2.81

Models from publications ICRP 30, 54, 66, 67, 69 were indicated by participants, also present in tabulations as ICRP 78 or IAEA BSS 115.

For comparing of E(50) derived with the different models, the participants are sorted into the following categories:

1. Participants using ICRP 66 for respiratory tract plus ICRP 67 and 69 for systemic phase (participant IDs 5, 20, 29)

2. Participants using ICRP 66 for respiratory tract plus ICRP 30 for systemic phase (participant IDs 1, 4, 6, 7, 14, 17, 18, 21, 34, 39, 46)

3. Participants using ICRP 30 for respiratory tract plus ICRP 30 for systemic phase (participant IDs 25, 30, 33, 42, 48, 49)

Table 4.3.5.5 lists the GM and GSD values for the three categories. There is no systematic dependance of the values on the type of models used. However, for the two isotopes of uranium the

behaviour seems to be similar: the values of ICRP 30 users lie between those related to new models and those of ICRP 66+30 users.

The participants using ICRP 30 models made the particle size correction of dose coefficients according to the suggested methodology (participant ID 42, 48, 49). The participants have used different options in choosing AMAD values in relation to the computational tools to them available. When there is no possibility ofusing the values suggested in the case description the default values, 1 or 5 μm AMAD, were used (participant ID 20). The majority of participants used M, S, S types (or W,Y,Y class) for absorption type or inhalation class respectively for Po, U and Th. Other participants indicated all S or Y type and also all W type (ID 49). In one case M, M, S choice has been made (ID 5).

Table 4.3.5.5: Comparison between models used

		E(50)		
		Category 1	Category 2	Category 3
	Number of answers	3	11	6
^{210}Po	GM (μSv)	3228	3509	2139
	GSD	1.14	1.20	1.58
^{238}U+ daughters	GM (μSv)	198	448	311
	GSD	2.19	1.86	3.14
^{235}U+ daughters	GM (μSv)	7.4	16.9	12.5
	GSD	3.68	2.26	2.98
^{232}Th+ daughters	GM (μSv)	111	98	441
	GSD	2.90	2.33	1.75

The results do not show large spread of values of intake, especially for ^{210}Po evaluation. Committed effective doses show greater variability due to different assumptions mainly related to secular equilibrium of the daughter radionuclides in the natural families. For LUDEP users general agreement on dose coefficients when using ICRP 30 models for the systemic phase has been found. Only 3 participants used all the new ICRP models both for the respiratory tract and the systemic modelling and also in this case the behaviour of the daughter radionuclides in the body is linked to that of the parents. For future applications in the field of dose assessment of naturally occurring radionuclides these aspects must be carefully considered also for providing mathematical tools to handle increasing computational complexities.

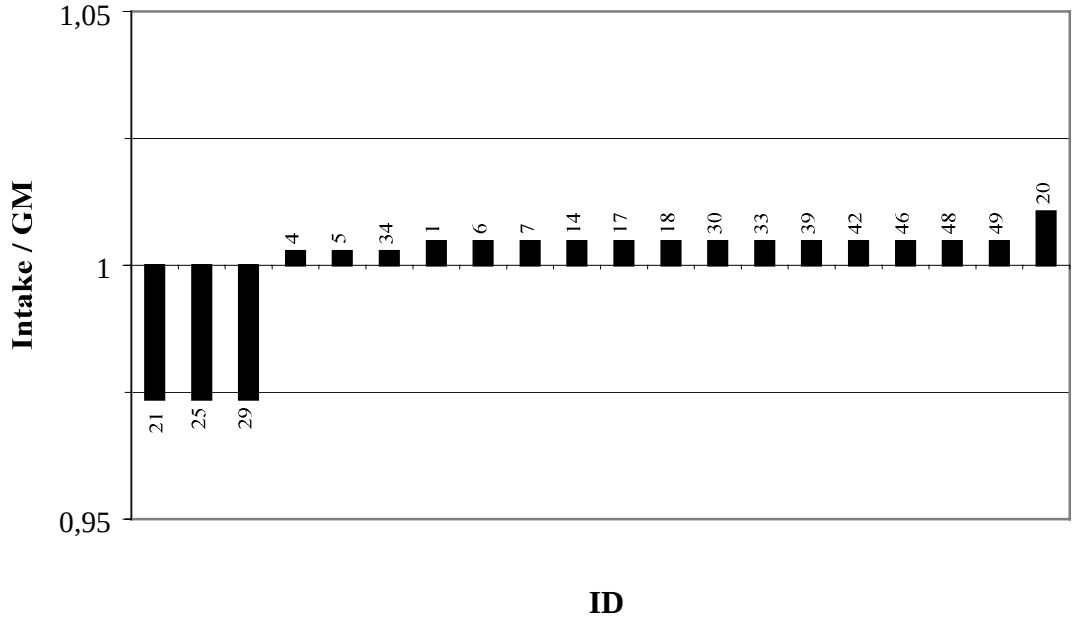


Fig. 4.3.5.1 : Results of the individual participants (ID): Intake of ^{210}Po normalised to the geometric mean (GM = 1027 Bq ; GSD= 1.01; 98.8 % C.I. = 1002 – 1053 Bq)

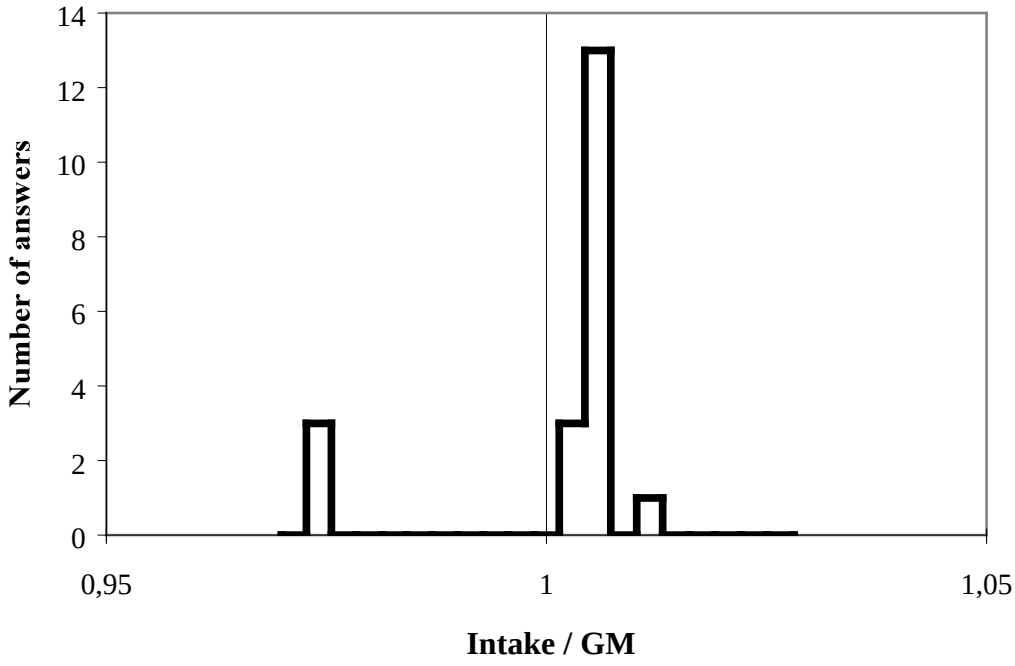


Fig. 4.3.5.2 : Frequency distribution of the results: Intake of ^{210}Po normalised to the geometric mean (GM = 1027 Bq ; GSD= 1.01; 98.8 % C.I. = 1002 – 1053 Bq)

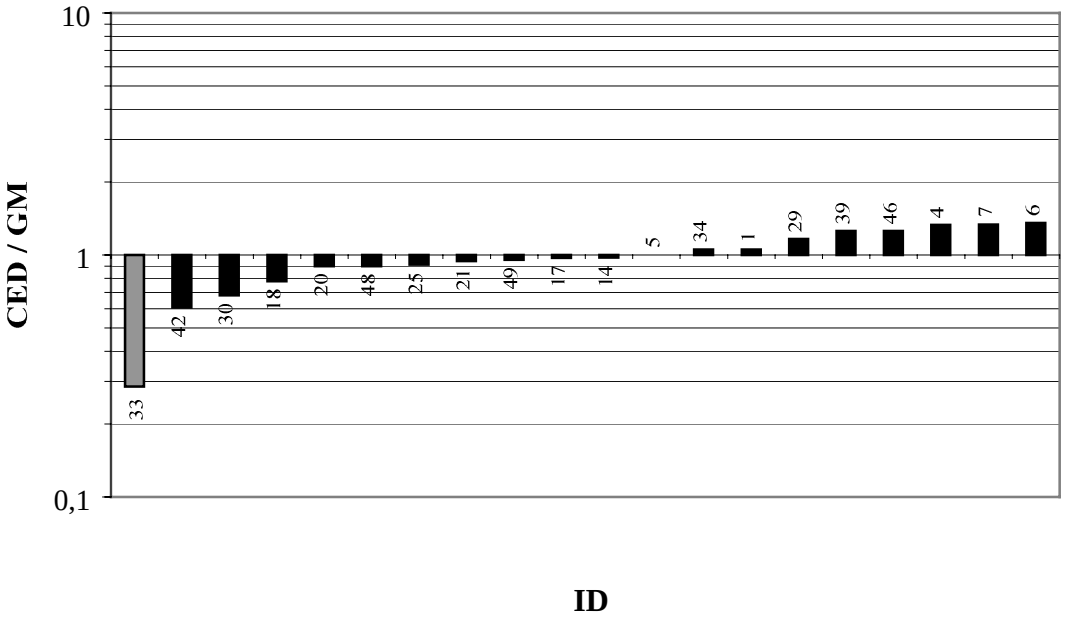


Fig. 4.3.5.3 : Results of the individual participants (ID): Committed effective dose of ^{210}Po normalised to the geometric mean (GM = 3180 μSv ; GSD= 1.25; 98.8 % C.I. = 1820 – 5555 μSv)

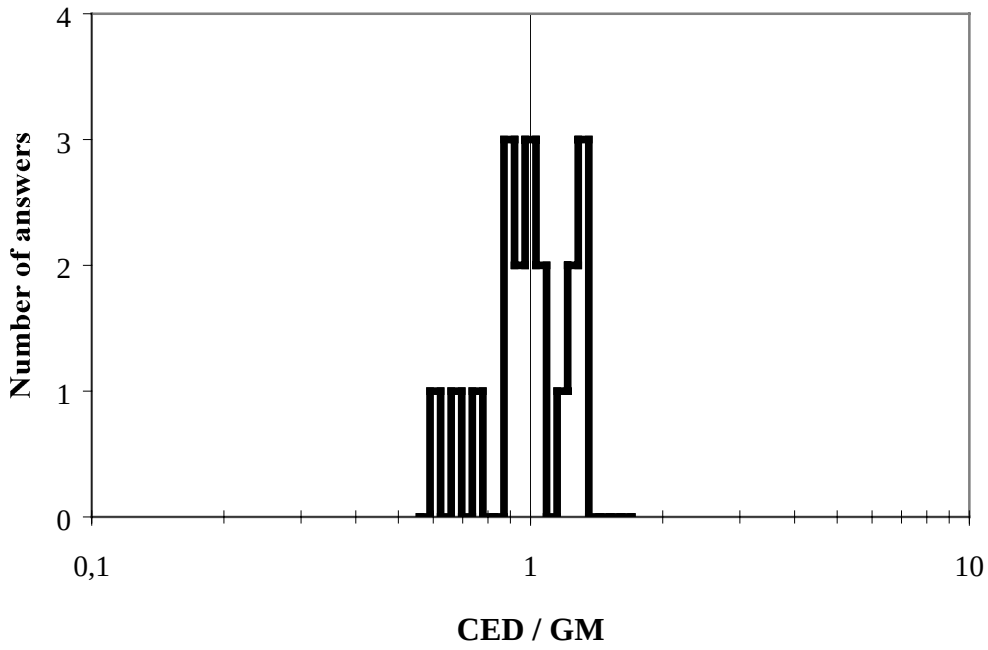


Fig. 4.3.5.4 : Frequency distribution of the results: Committed effective dose of ^{210}Po normalised to the geometric mean (GM = 3180 μSv ; GSD= 1.25; 98.8 % C.I. = 1820 – 5555 μSv)

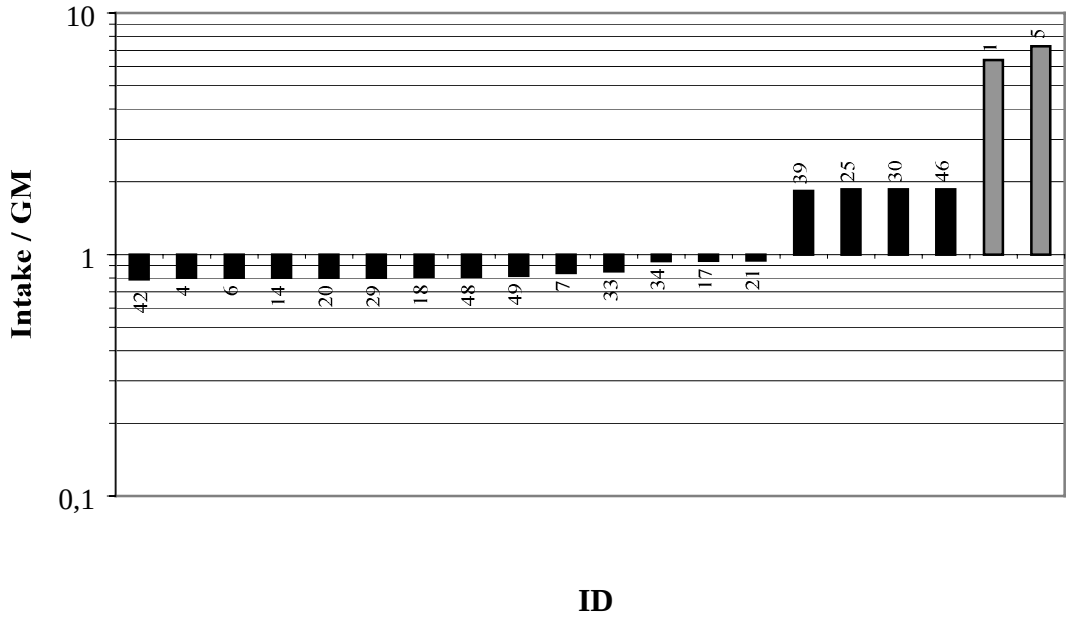


Fig. 4.3.5.5 : Results of the individual participants (ID): Intake of ^{238}U normalised to the geometric mean (GM = 6.98 Bq ; GSD= 1.41; 98.8 % C.I. = 2.96 – 16.48 Bq)

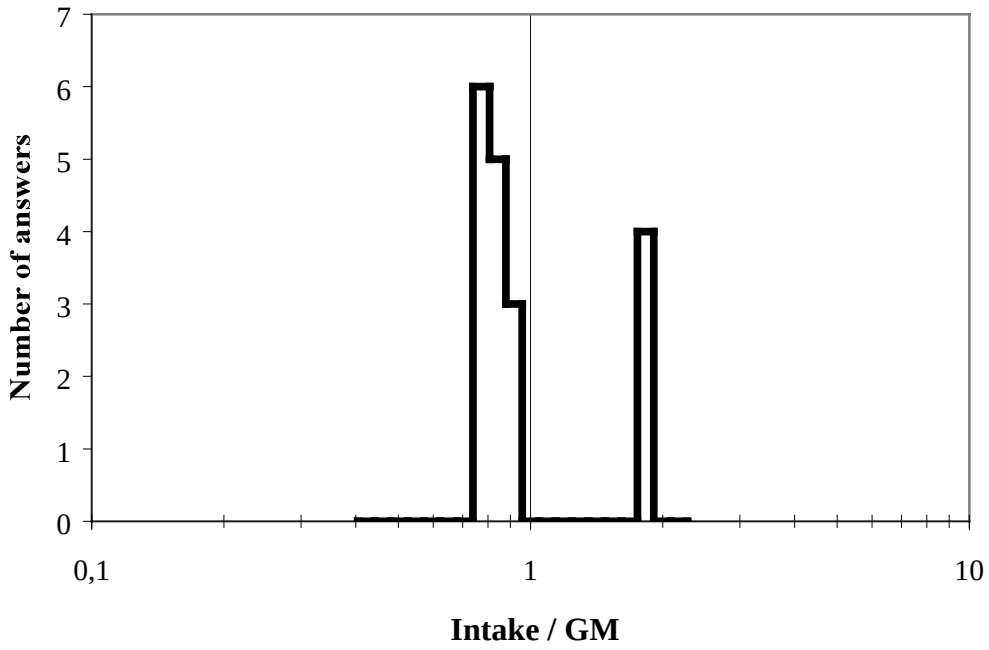


Fig. 4.3.5.6 : Frequency distribution of the results: Intake of ^{238}U normalised to the geometric mean (GM = 6.98 Bq ; GSD= 1.41; 98.8 % C.I. = 2.96 – 16.48 Bq)

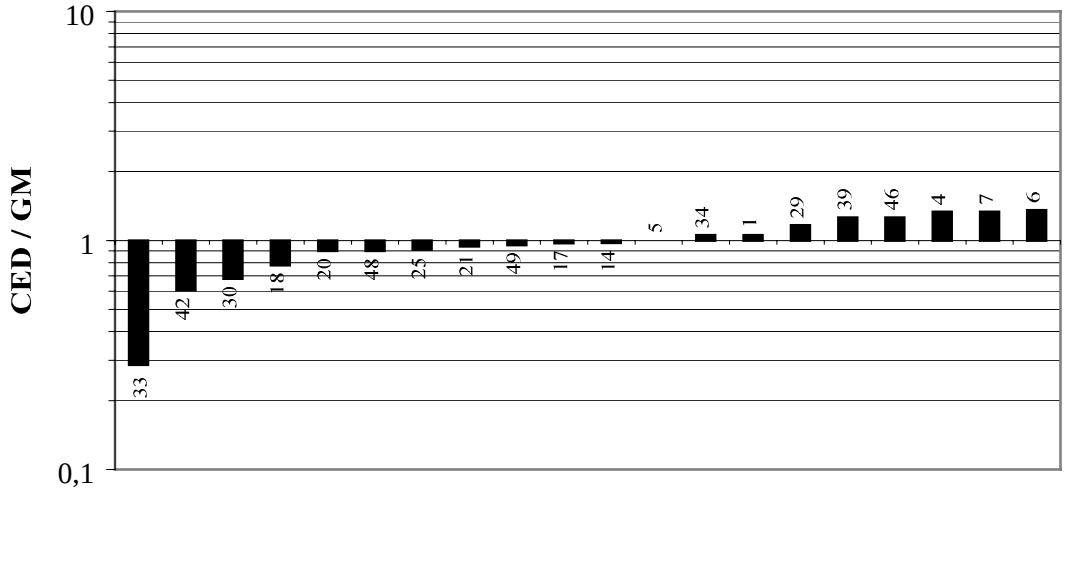


Fig. 4.3.5.7 : Results of the individual participants (ID): Committed effective dose of ^{238}U + daughters normalised to the geometric mean (GM = 355 μSv ; GSD= 2.31; 98.8 % C.I. = 44 – 2879 μSv)

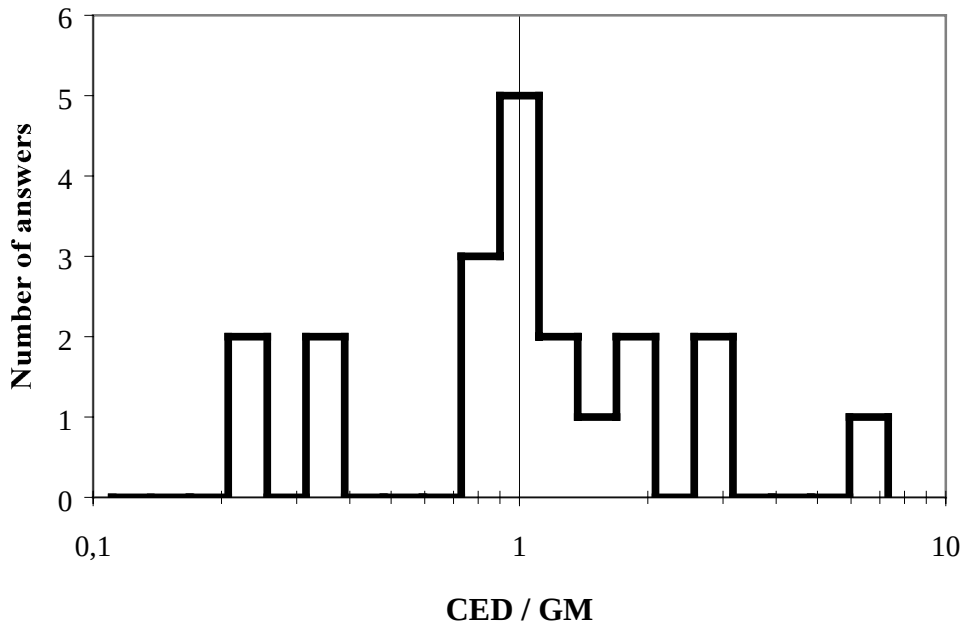


Fig. 4.3.5.8 : Frequency distribution of the results: Committed effective dose of ^{238}U + daughters normalised to the geometric mean (GM = 355 μSv ; GSD= 2.31; 98.8 % C.I. = 44 – 2879 μSv)

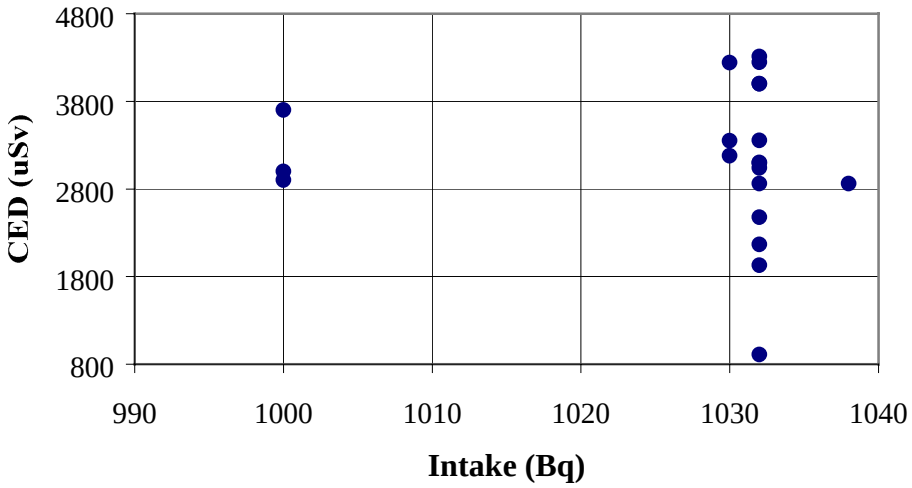


Fig. 4.3.5.9 : Committed effective dose versus intake for ^{210}Po.

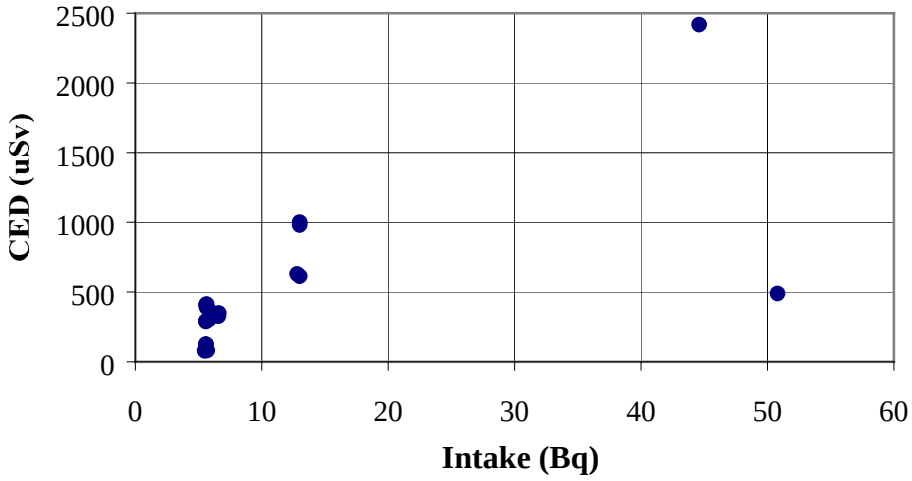


Fig. 4.3.5.10: Committed effective dose versus intake for ^{238}U + daughters.

4.3.6 Accidental intake of ^{239}Pu

This case has been designed on the basis of real data, however, the original information has been reduced and modified to some extend. The original case is one of the best-documented cases of a single intake of Trans-uranium elements worldwide. There is a set of excretion and organ burden data from the first day after intake over a time period of almost ten years available. The data are good for fitting to bio-kinetic models because

(i) the values are relative high and thus the statistical errors are relative small and

(ii) the data were not affected by any chelation therapy. In addition, there is quite a lot of additional information, such as the chemical form, the original nuclide composition and the particle size.

The original case was already included in a prior intercomparison, which revealed an average intake of about 19 kBq ^{239}Pu and an average effective committed dose of about 0.8 Sv. The evaluations in the prior intercomparison were carried out using all the data collected on this case consisting of almost 100 measurements. So these values may be considered as good estimates of the intake and the effective dose. In routine incorporation monitoring, however, this amount of data is never obtained. Thus, for Case 6 the amount of data was reduced to an amount which is typically obtained in routine monitoring cases. Two different sets of data were created, the first one (Subject A) representing some selected data in the original form and the second one (Subject B) representing some other selected data scaled by the factor 3.

Thirty-three participants provided answers for this case (see Annex F6.2). Most of the answers were complete, only four participants did not indicate some results based on urine and/or on faeces. There have been identified 23 and 20 outliers for Subject A and Subject B, respectively. Most of the outliers (18) refer to respective results for Subject A and Subject B. As can be seen from Annex F6.2 the median of the data is in general much closer to the geometric mean than to the arithmetic mean, this confirming that the results belong to a log-normal distribution rather than to a normal distribution.

As can be seen in Fig 4.3.6.1 for the best estimate for intake for subject A, the frequency distribution is bimodal and reflects the use of the old or new lung model. Therefore the results were split between results calculated applying the old or new lung model. In these two groups of results, 15 and 13 outliers have been identified for subject A and B respectively. Now the median of the data is in general closer to the arithmetic mean than to the geometric mean indicating that the results belong to a normal distribution in each of the two groups old and new lung model.

Fig 4.3.6.2 to Fig 4.3.6.5 show the frequency distributions of the best estimates of intake for subject A calculated with the old and new lung models. Fig. 4.3.6.6 to Fig 4.3.6.9 show the best estimates of the committed effective dose for subject A calculated with the old and new lung models.

Tables 4.3.6.1 and 4.3.6.2 summarise the general statistics of the results for subject A, neglecting the outliers and based on the model used for the evaluation, i.e. the old lung model (ICRP 30 and ICRP 54), the new lung model (ICRP 66 and ICRP 78) respectively. For subject B, these data are found in Tables 4.3.6.3 and 4.3.6.4. As can be seen, the intake based on the old lung model is a factor of, at least, 2 lower than the intake based on the new lung model, whereas the committed effective dose based on the old lung model is a factor of 2 higher than that based on the new lung model.

For the evaluations carried out with the new lung model, the geometric means of the estimates of the intake for subject A based on faecal data alone is a factor of 2 different from that based on urine data alone. The correspounding factor for subject B is only 1.13. For evaluation based on the old lung model, there is at least a factor 4 between the geometric mean of intake based on urine and faeces. On the other hand the agreement between the geometric mean of the committed effective dose based on urine and based on faeces is similar for evaluation based on both models for subject A and B.

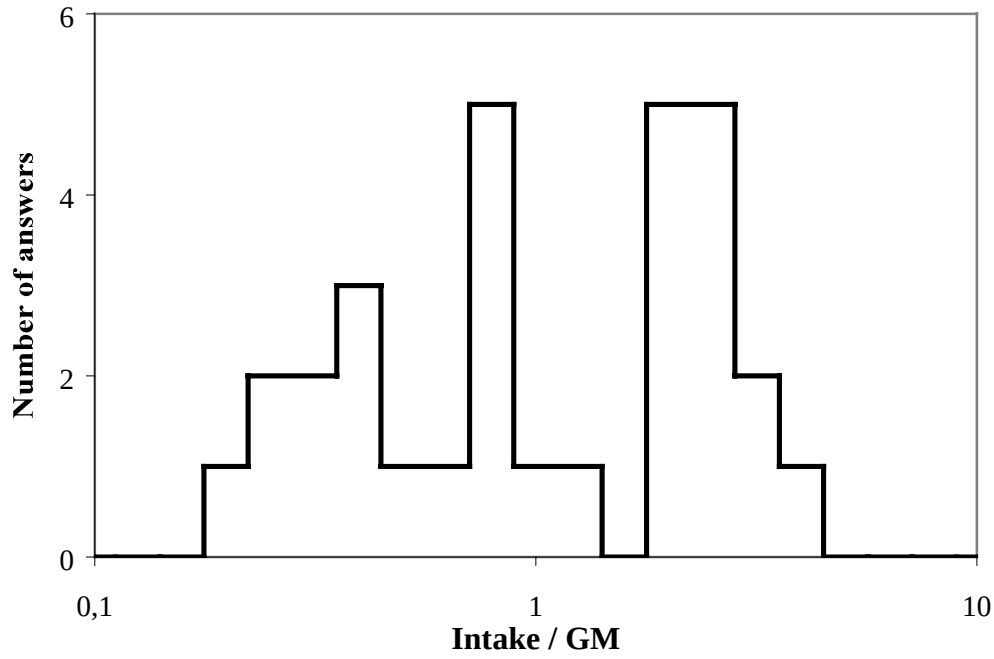


Fig. 4.3.6.1: Frequency distribution of the results: Best estimates for the intake of subject A normalised to the geometric mean (GM = 17.2 kBq, GSD = 2.52)

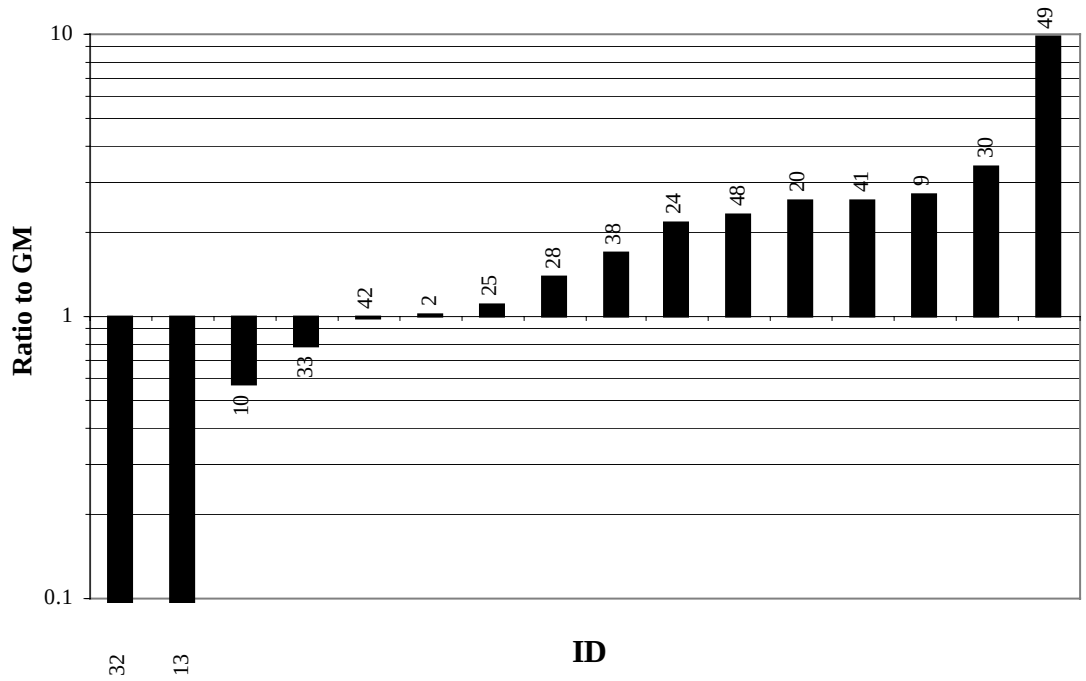


Fig. 4.3.6.2: Results of the individual participants (ID): Best estimates for the intake of subject A using the old lung model (ICRP 30), normalised to the geometric mean (GM = 5.9 kBq, GSD = 5.64)

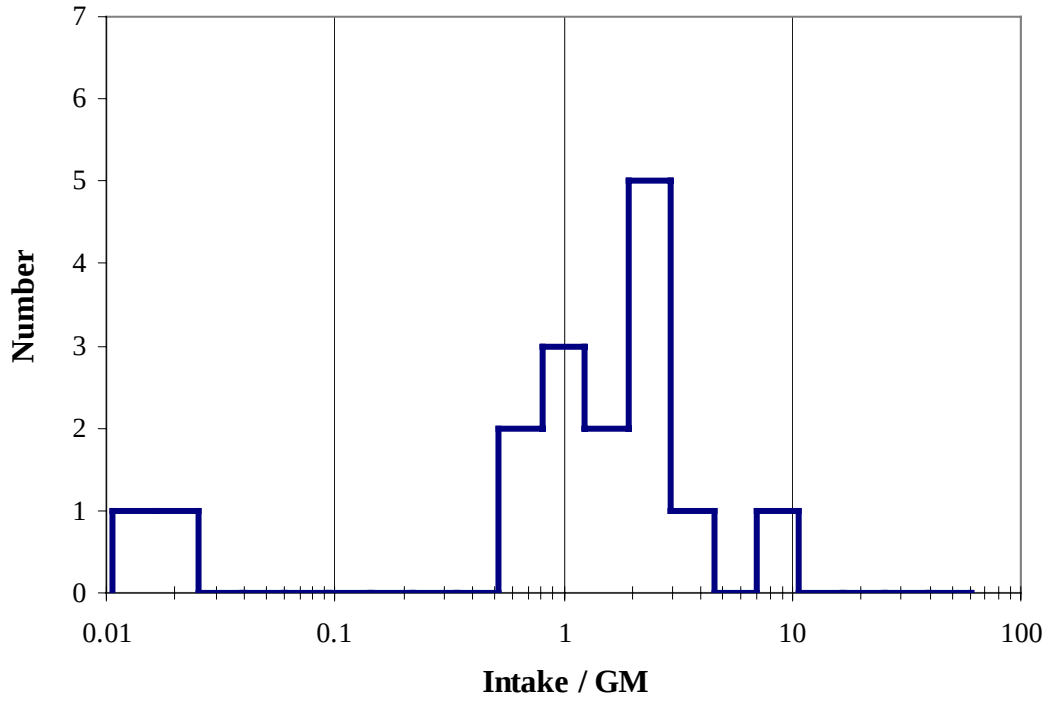


Fig. 4.3.6.3: Frequency distribution of the results: Best estimates for the intake of subject A using the old lung model (ICRP 30), normalised to the geometric mean (GM = 5.9 kBq, GSD = 5.64)

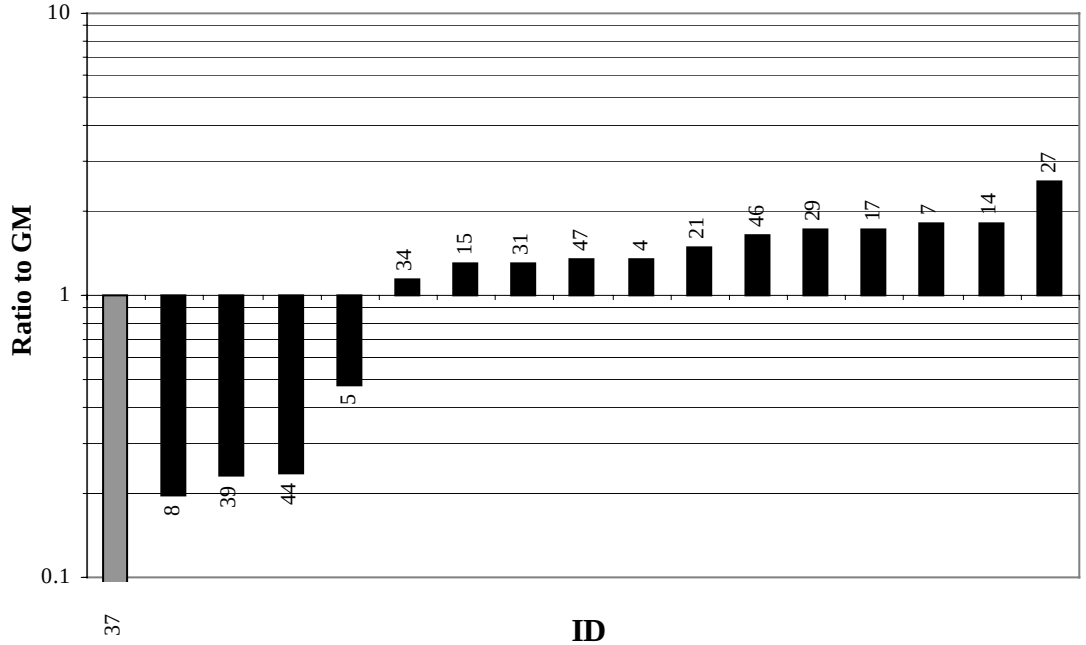


Fig. 4.3.6.4: Results of the individual participants (ID): Best estimates for the intake of subject A using the new lung model (ICRP 66), normalised to the geometric mean (GM = 27 kBq, GSD = 2.29)

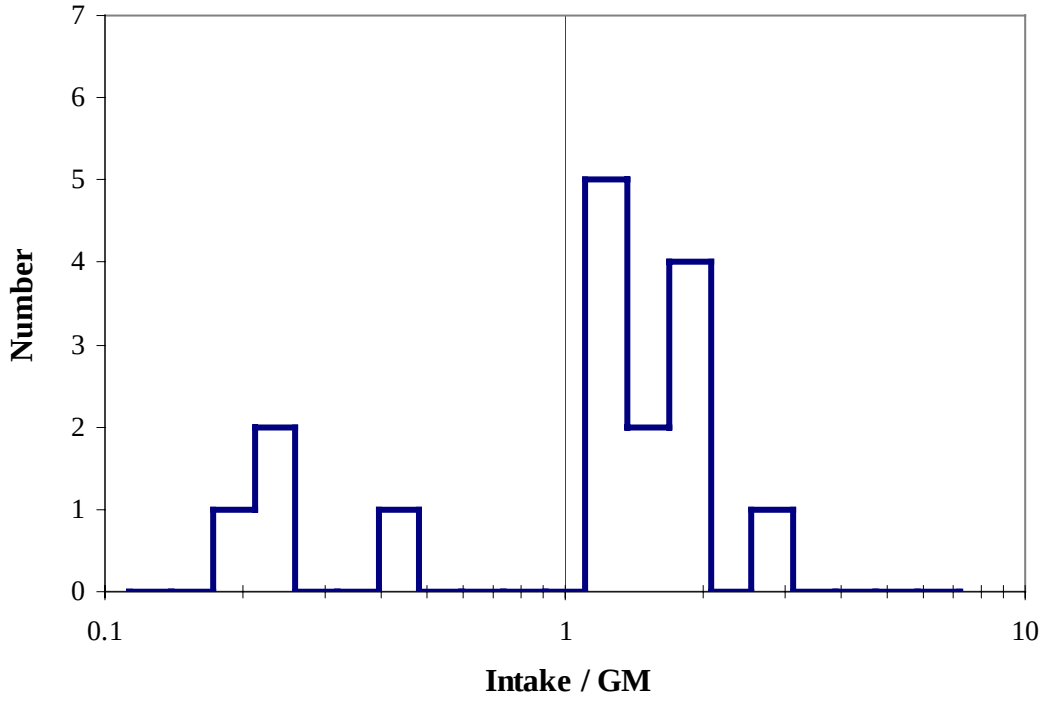


Fig. 4.3.6.5: Frequency distribution of the results: Best estimates for the intake of subject A using the new lung model (ICRP 66), normalised to the geometric mean (GM = 27 kBq, GSD = 2.29)

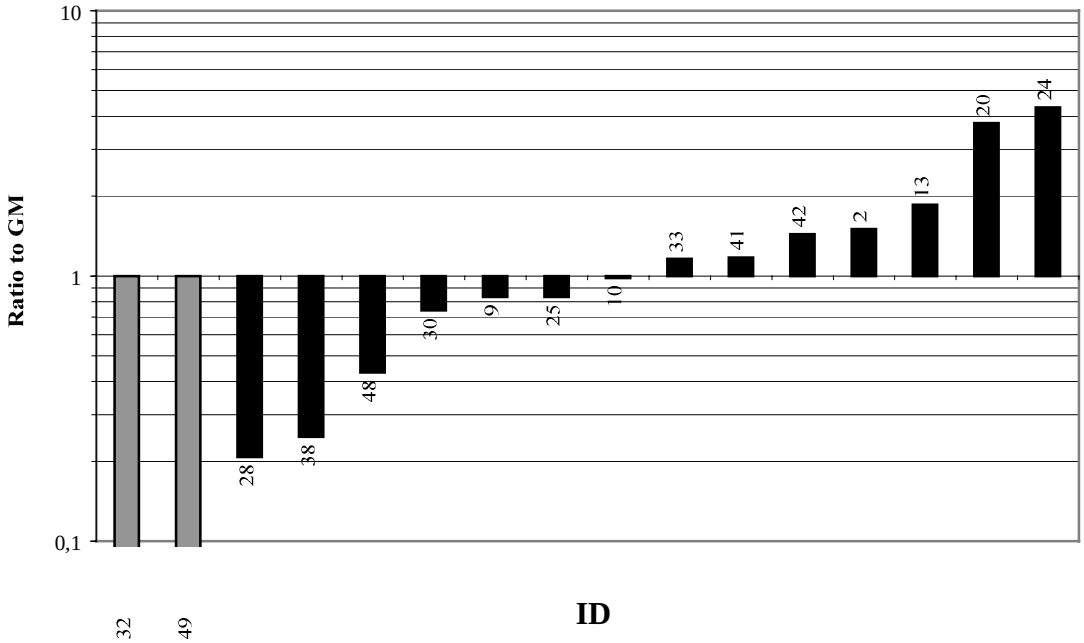


Fig. 4.3.6.6.: Results of the individual participants (ID): Best estimates for the committed effective dose of subject A using the old lung model (ICRP30), normalised to the geometric mean (GM = 324 mSv, GSD = 2.39)

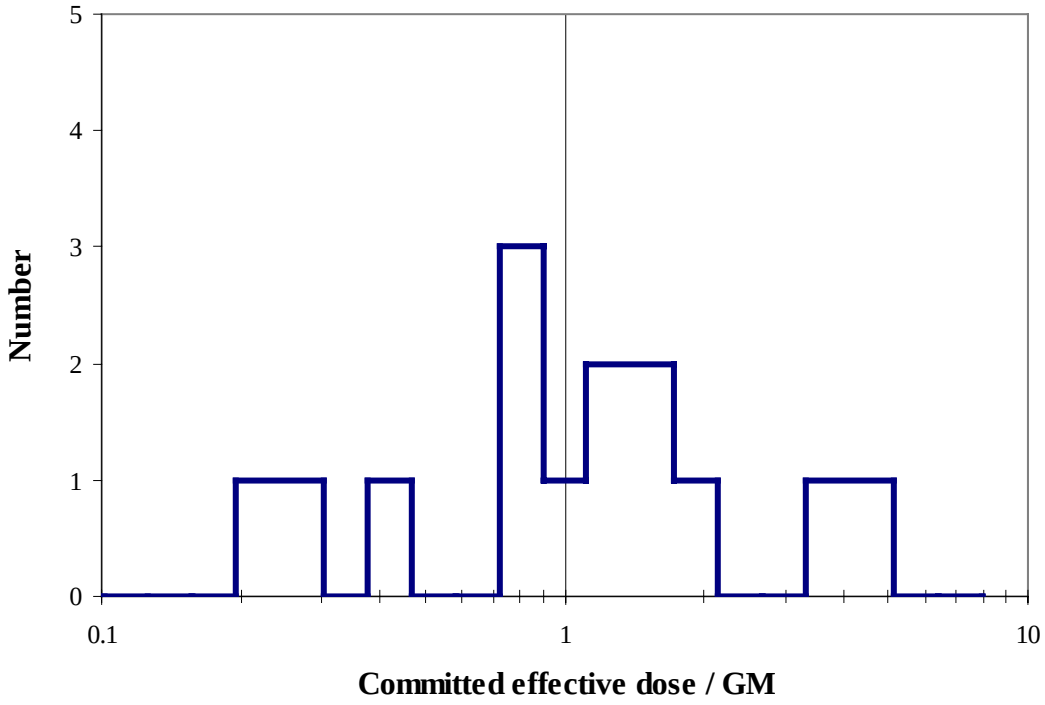


Fig. 4.3.6.7.: Frequency distribution of the results: Best estimates for the committed effective dose of subject A using the old lung model (ICRP30), normalised to the geometric mean (GM = 324 mSv, GSD = 2.39)

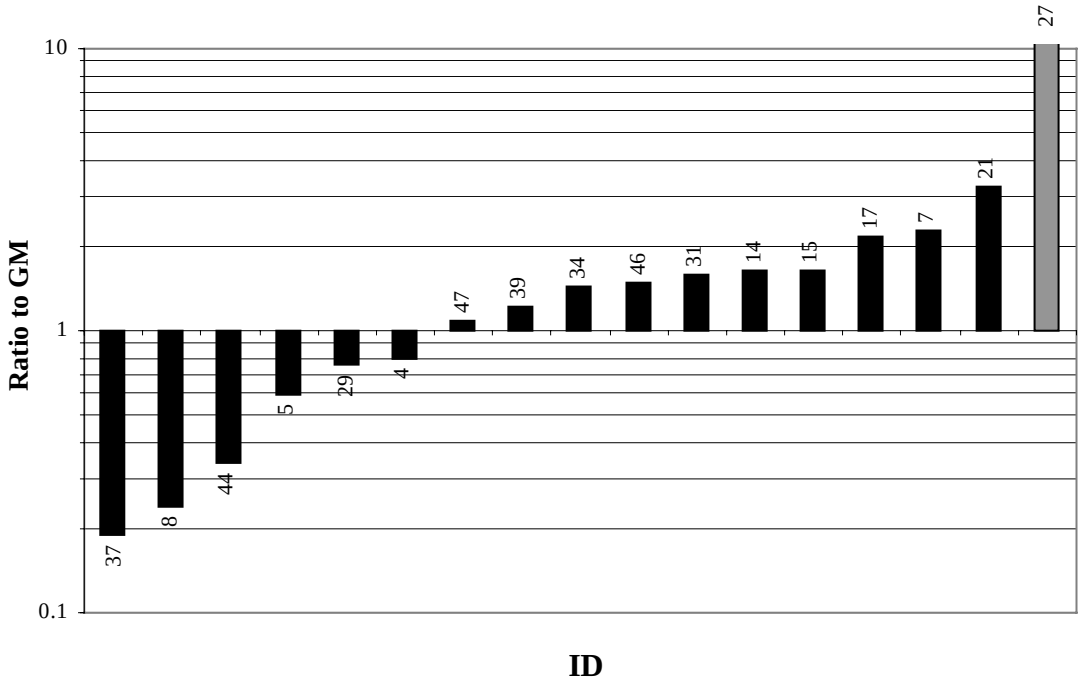


Fig. 4.3.6.8.: Results of the individual participants (ID): Best estimates for the committed effective dose of subject A using the new lung model (ICRP66), normalised to the geometric mean (GM = 185 mSv, GSD = 2.27)

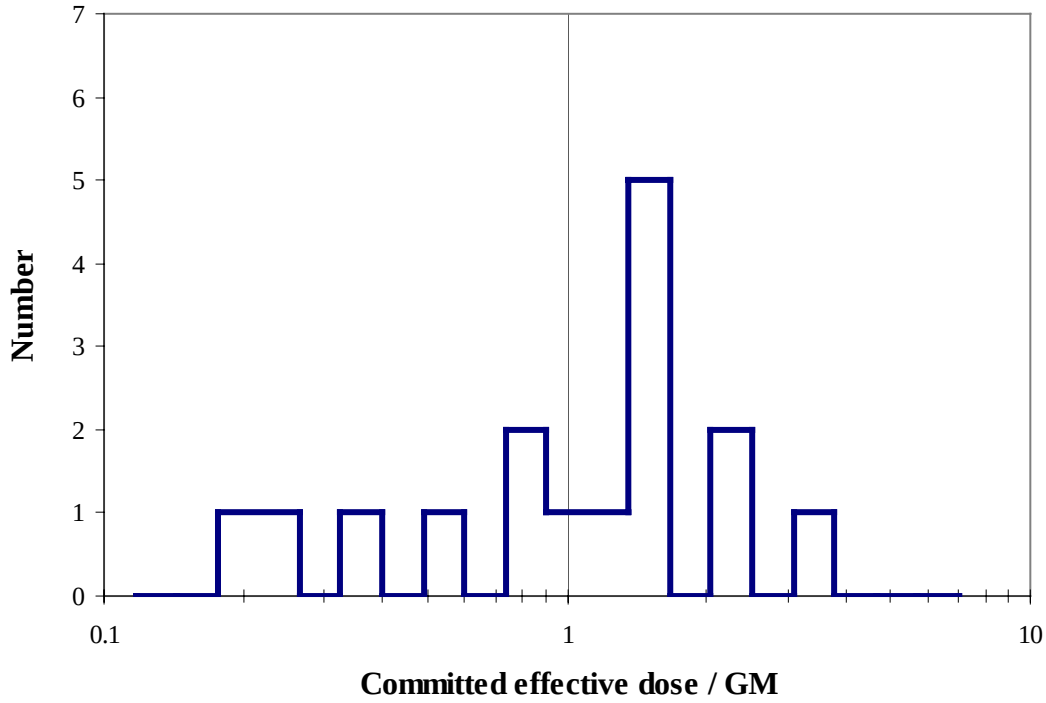


Fig. 4.3.6.9.: Frequency distribution of the results: Best estimates for the committed effective dose of subject A using the new lung model (ICRP66), normalised to the geometric mean (GM = 185 mSv, GSD = 2.27)

The intake and committed effective dose estimates based on faeces are higher than the estimates based on urine for evaluations with the old lung model for subject A and B. On the other hand, when the new lung model is used the intake and the committed effective dose based on the urine is higher than the estimates based on faeces for subject A. With the new lung model and for subject B, the estimates of the intake and of the committed effective dose are nearly equivalent when based on urine and faeces.

Ten participants based their best estimates on urine data alone, 8 on faecal data alone, 6 on the average of the estimates obtained using the urine and faecal data, and 5 on the weighted average of the estimates obtained using the urine and faecal data. However, a few participants used a different procedure for the best estimates when considering the intake or the committed effective dose. For the intake, the geometric mean of the best estimates is always between the intake based on urine and faeces. For the committed effective dose, the geometric mean of the best estimates is nearer to the dose based on the faeces for evaluations with the old lung model and nearer to the dose based on the urine for evaluations with the new lung model for subject A. This reflect the fact that for evaluations using the old model, the faeces estimate has been most used for the best estimate. On the contrary, for evaluations based on the new lung model, the urine estimate has been mainly used for the best estimate. The situation is not as clear for subject B.

Another point is that the geometric mean of the best estimates of intake based on the old lung model is about a factor 5 smaller for subject A and 6 times smaller for subject B than the intake based on the new lung model. On the other hand, for subject A, the geometric mean of the best estimates of the committed effective dose based on the old lung model is about a factor 2 higher than the dose based on the new lung model. This factor is only 1.15 for subject B.

Table 4.3.6.1: Statistics of the results (without outliers) for Subject A based on the old ICRP models (i.e. ICRP 30 and ICRP 54)

	Total intake of ^{239}Pu			Committed effective dose due to total intake		
	Based on urine	Based on faeces	Best estimate	Based on urine	Based on faeces	Best estimate
Number of estimates	14	14	16	14	13	14
Geometric mean	2.8 kBq	11.3 kBq	5.9 kBq	171 mSv	320 mSv	324 mSv
Geometric standard deviation	4.86	2.12	5.64	3.53	2.38	2.39
Arithmetic Mean	5.2 kBq	15.0 kBq	12.1 kBq	266 mSv	449 mSv	451 mSv
Arithmetic Std	4.3 kBq	13.6 kBq	13.5 kBq	179 mSv	409 mSv	395 mSv
Maximum	15000 Bq	57680 Bq	57680 Bq	600 mSv	1400 mSv	1400 mSv
Minimum	69 Bq	3755 Bq	82.3 Bq	9.7 mSv	63 mSv	67 mSv

Table 4.3.6.2:Statistics of the results (without outliers) for Subject A based on the new ICRP models (i.e. ICRP 66 and ICRP 67)

	Total intake of ^{239}Pu			Committed effective dose due to total intake		
	Based on urine	Based on faeces	Best estimate	Based on urine	Based on faeces	Best estimate
Number of estimates	14	16	16	15	14	16
Geometric mean	43 kBq	21 kBq	27 kBq	175 mSv	115 mSv	185 mSv
Geometric standard deviation	1.30	2.23	2.29	2.70	1.92	2.27
Arithmetic mean	44 kBq	27 kBq	34 kBq	235 mSv	137 mSv	238 mSv
Arithmetic Std	12 kBq	16 kBq	18 kBq	126 mSv	77 mSv	152 mSv
Maximum	72000 Bq	64000 Bq	69000 Bq	419 mSv	267 mSv	600 mSv
Minimum	29000 Bq	5230 Bq	5300 Bq	17 mSv	37 mSv	35 mSv

Table 4.3.6.3:Statistics of the results (without outliers) for Subject B based on the old ICRP models (i.e. ICRP 30 and ICRP 54)

	Total intake of ^{239}Pu			Committed effective dose due to total intake		
	Based on urine	Based on faeces	Best estimate	Based on urine	Based on faeces	Best estimate
Number of estimates	14	14	16	14	15	15
Geometric mean	0.54 kBq	3.2 kBq	1.29 kBq	34 mSv	41 mSv	61 mSv
Geometric standard deviation	5.56	2.33	5.96	4.43	7.62	4.21
Arithmetic Mean	1.12 kBq	4.4 kBq	3.2 kBq	62 mSv	132 mSv	136 mSv
Arithmetic Std	0.99 kBq	4.1 kBq	4.2 kBq	51 mSv	211 mSv	208 mSv
Maximum	3200 Bq	17003 Bq	17003 Bq	170 mSv	829 mSv	829 mSv
Minimum	8 Bq	805 Bq	30 Bq	1.1 mSv	0.304 mSv	2.38 mSv

Table 4.3.6.4:Statistics of the results (without outliers) for Subject B based on the new ICRP models (i.e. ICRP 66 and ICRP 67)

	Total intake of ^{239}Pu			Committed effective dose due to total intake		
	Based on urine	Based on faeces	Best estimate	Based on urine	Based on faeces	Best estimate
Number of estimates	15	15	16	15	14	16
Geometric mean	7.5 kBq	8.5 kBq	7.6 kBq	35 mSv	46 mSv	53 mSv
Geometric standard deviation	2.34	1.57	2.12	2.53	2.17	2.33
Arithmetic mean	10.1 kBq	9.3 kBq	9.5 kBq	47 mSv	61 mSv	73 mSv
Arithmetic Std	7.4 kBq	3.7 kBq	5.5 kBq	33 mSv	55 mSv	62 mSv
Maximum	23000 Bq	17000 Bq	17000 Bq	123 mSv	226 mSv	226 mSv
Minimum	1500 Bq	3000 Bq	1500 Bq	3.8 mSv	11 mSv	12 mSv

As stated earlier, the data set for subject B has been scaled down by a factor 3 compared to subject A. In the best estimates, the factor between subject A and B is about 5 for the results based on the old lung model and around 3.5 for those based on the new lung model.

Most of the participants assumed heavy insoluble compounds. So 12 out of 16 participants using the old lung models assumed retention class Y compounds and 15 out of 17 participants using the new models assumed absorption type S compounds. Table 4.3.6.5 – 4.3.6.8 show some statistics with respect to the particle size assumptions. Many participants used the default AMAD values, i.e. 1 μm for the old models and 5 μm for the new models, but there are also many participants using 10 μm. As can be seen from Tables 4.3.6.5 and 4.3.6.6, there is a systematic dependence of the intake estimates on the assumed AMAD value. The geometric mean of the estimated intakes is almost doubled when increasing the AMAD value from 1 μm to 5 μm (Table 4.3.6.5), or from 5 μm to 10 μm (Table 4.3.6.6).

The geometric standard deviation of the intake estimates based on the old models is coming close to one in the different categories, this indicating that the scattering of the intake values is mainly due to the AMAD value. The geometric mean of the committed effective dose, however, doesn't show a respective dependence, and the geometric standard deviation is not coming close to one in all the AMAD categories. This is due to the fact that when not using the default values for the AMAD an incorrect dose coefficient has been used in the calculation. This is particularly true for estimates based on the old lung model. In fact, if correct dose coefficients have been used, the geometric standard deviation of the intakes and of the committed effective doses should be similar. When a large difference is observed between the geometric standard deviation of the intakes and of the effective doses, incorrect dose coefficients have been used as in the case of 5 and 10 μm AMAD for the old lung model.

Table 4.3.6.5:Geometric and arithmetic mean and standard deviation of estimated intakes and committed effective doses for subject A based on the old ICRP lung model for retention class Y and different AMAD values

	Particle size (μm AMAD)		
	1	5	10
Intake (Best Estimate)			
Number of Estimates	4	2	5
Geometric mean (kBq)	4.80	7.26	5.32
Geometric standard deviation	1.30	1.17	8.40
Arithmetic mean ± std (kBq)	4.9 ± 1.2	4.9 ± 4.2	11.2 ± 6.6
Committed Effective Dose (Best Estimate)			
Number of Estimates	4	2	5
Geometric mean (mSv)	405	135	360
Geometric standard deviation	1.22	2.67	2.75
Arithmetic mean ± std (mSv)	411 ± 78	169 ± 143	510 ± 439

Table 4.3.6.6:Geometric and arithmetic mean and standard deviation of estimated intakes and committed effective doses for subject A based on the new ICRP lung model for absorption type S and different AMAD values

	Particle Size (µm AMAD)	
	5	10
Intake (Best Estimate)		
Number of Estimates	10	4
Geometric mean (kBq)	19.8	41
Geometric standard deviation	2.48	1.16
Arithmetic mean ± std (kBq)	27 ± 17	41 ± 6
Committed Effective Dose (Best Estimate)		
Number of Estimates	10	4
Geometric mean (mSv)	209	221
Geometric standard deviation	2.35	1.39
Arithmetic mean ± std (mSv)	272 ± 173	230 ± 70

Tab. 4.3.6.7:Geometric and arithmetic mean and standard deviation of estimated intakes and committed effective doses for subject B based on the old ICRP lung model for retention class Y and different AMAD values

	Particle size (µm AMAD)		
	1	5	10
Intake (Best Estimate)			
Number of Estimates	4	3	5
Geometric mean (kBq)	1.17	1.45	1.26
Geometric standard deviation	1.40	1.74	8.16
Arithmetic mean ± std (kBq)	1.21 ± 0.35	1.05 ± 1.06	2.6 ± 1.6
Committed Effective Dose (Best Estimate)			
Number of Estimates	4	2	5
Geometric mean (mSv)	98	39	87
Geometric standard deviation	1.30	3.02	2.96
Arithmetic mean ± std (mSv)	100 ± 24	51 ± 48	131 ± 124

Tab. 4.3.6.8:Geometric and arithmetic mean and standard deviation of estimated intakes and committed effective doses for subject B based on the new ICRP lung model for absorption type S and different AMAD values

	Particle Size (µm AMAD)	
	5	10
Intake (Best Estimate)		
Number of Estimates	10	4
Geometric mean (kBq)	5.4	11.9
Geometric standard deviation	2.09	1.40
Arithmetic mean ± std (kBq)	6.8 ± 4.6	12.4 ± 3.9
Committed Effective Dose (Best Estimate)		
Number of Estimates	10	4
Geometric mean (mSv)	56	66
Geometric standard deviation	2.61	1.34
Arithmetic mean ± std (mSv)	83 ± 75	69 ± 21

The averages of intake based on the old lung model are in relative good agreement with the results of the prior intercomparison exercise, which was based on the old lung model. This applies also to the results based on the new lung model if we take into account the factor 2 observed between the old and new models. Thus the amount of data is not that important for the intake assessment. The averages of the committed effective dose, however, are a factor 2 lower than the respective values of the prior intercomparison. This reflects the importance of the amount of data for the adjustment of the model.

4.3.7 Intake of ^{239}Pu long time ago

This case is of special interest with respect to the recent limitation of life-span dose. There are quite a lot of Plutonium workers who were exposed many years ago when the limits for occupational exposure of Plutonium have been much higher than they are now. With respect to the limitation of the life-span dose, however, the exposure now has to be re-evaluated for those workers who are still occupationally exposed to Plutonium, taking into account the recent biokinetic models. The monitoring procedures in those years have been not that sensitive and thus in most cases the database is very poor. The case described here gives a realistic example for the problems arising from the poor database.

In 1990, routine incorporation monitoring resulted in significant excretion rates of Plutonium in urine and feces for a person working for more than 25 years in the institute. Room air monitoring, however, gave not any indication of a Plutonium exposure in the time before. So the working history of the person has been studied in detail. The files 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 (5 pCi). Thus, no additional investigations have been performed at this time. Between 1965 and 1989 routine incorporation monitoring resulted in 4 positive urine samples out of a total of 56 samples. The highest value was 40.7 mBq (11 pCi). After having found the positive results in 1990, however, the case had to be evaluated once more, taking into account all information available, i.e. all Plutonium excretion data for urine and feces as well as some body counting data for the Am-241 content of lungs, liver and the skeleton. Most of these data, however, are not significant (below LLD).

All this information was given to the participants of the intercomparison and 28 participants provided answers for the case. Most of them (21) provided all required data. Only one participant did not provide estimates based on fecal excretion data, and 7 participants did not provide estimates based on organ data. This is a very good response with respect to the difficulties involved in this case.

The handling of the data below LLD is of essential importance. As can be seen from Table F7.2.5 in the Annex F7, about half of the participants ignored all the data below LLD. Two participants used them as upper bounds for the fitted functions, one participant set them to 80 % of the LLD, one participant to 10 % of the LLD and one other participant set them equal to zero with the standard deviation to be equal to the LLD.

Only four participants used all data for the evaluation, four other participants used all excretion data together with the lung data and one participant used all excretion data together with the skeleton data. Eight participants used all excretion data except the relative high urine value of day 1108 and 7 other participants used only the excretion data after day 9000, all in connection with different combinations of the organ data. So the data handling was very different among the participants.

Most of the participants assumed the intake to be due to an acute inhalation. One participant (ID 6) assumed an additional intake via wound, and one other participant (ID 46) assumed the whole intake to be due to wound deposition (chronic injection via wound). The intake estimates of the latter participant were all identified as outliers whereas the dose estimates were well within the range of the other dose estimates. In total 18 outliers have been identified which is about 8 % of all submitted data.

For interpretation of the data, various combinations of the ICRP models have been applied. Most of the participants provided the respective information. In some cases, however, this information was not complete or was ambiguous (Table F7.2.4).

As can be seen from Table F7.2.1, the geometric mean in general is smaller than the arithmetic mean, suggesting that the values belong to a log-normal distribution rather than to a normal distribution. There is a good agreement between the arithmetic mean of the estimates based on urine and feces, this being mainly due to the fact that the arithmetic mean is dominated by the largest numbers. The geometric mean of the best estimates based on urine, however, is significant lower than that of the corresponding values based on feces. So the geometric mean reflects the model inconsistency of the assessment much better than the arithmetic mean.

Table 4.3.7.1 below lists the geometric mean and the geometric standard deviation derived from all data without outliers. The geometric mean of the best estimate of the intake is higher than the geometric mean of the intake based on urine, feces as well as based on the Am-241 organ activity. This is due to the fact that some participants defined conservatively the highest estimate to be the best estimate. The geometric standard deviation of the intake varies between 2.16 for the estimates based on feces and 4.44 for the estimates based on the Am-241 organ activity. On the other hand, the geometric standard deviation of the committed effective dose varies within only a very small range from 1.9 for the estimates based on urine to 2.25 for the estimates based on feces. This reflects that the systemic exposure can be derived from all data with more or less the same accuracy whereas the intake can be derived only from the feces values with a reasonable accuracy.

Table 4.3.7.2 shows the geometric mean and standard deviation of the best estimates for intake and committed effective dose based on the old models (i.e. ICRP30 and ICRP54), the new models (i.e. ICRP66 and ICRP67) and on combination of the old and new models (i.e. ICRP30/54 for the systemic retention and excretion, respectively, and ICRP66 for the respiratory tract). As can be seen from this table the intake based on the old models is about a factor 2 smaller than the intake based on the new models, whereas the committed effective dose based on the old models is a factor 2 higher than that based on the new models.

Table 4.3.7.1: General statistics of the results (without outliers)

	Total intake of Pu-239 and Pu-240				Committed effective dose due to total intake of Pu-239 and Pu-240			
	Based on urine	Based on feces	Based on Am-241 organ activity	Best estimate	Based on urine	Based on feces	Based on Am-241 organ activity	Best estimate
Number of answers	27	25	20	27	27	26	20	27
GM	10.9 kBq	19.9 kBq	13.9 kBq	13.2 kBq	257 mSv	397 mSv	352 mSv	347 mSv
GSD	3.3	2.16	4.44	3.8	1.9	2.25	2.06	2.16
Maximum	103000	50000	160000	103000	780	1800	2000	1800
Minimum	2000	5000	1544	2000	67.5	80	23.5	40

Tab. 4.3.7.2: Geometric mean and standard deviation of best estimates (without outliers) for intake and committed effective dose based on the old models (i.e. ICRP30 and ICRP54), the new models (i.e. ICRP66 and ICRP67) and on combination of old and new models (i.e. ICRP30/54 and ICRP66)

Applied models	Number of estimates	Intake (best estimate)		Committed effective dose (best estimate)	
		GM (kBq)	GSD	GM (mSv)	GSD
Old models (ICRP30, ICRP54)	13	9.96	4.01	467	2.26
New models (ICRP66, ICRP67)	11	17.1	.58	226	2.21
Combination (ICRP30/54, ICRP66)	3	17.3	4.85	208	2.66

In total 13 participants used the old ICRP lung model and 14 participant used the new ICRP lung model. One participant assumed moderate soluble material (class W) and all other participants assumed highly insoluble material (class Y and absorption type S, respectively). Most of the participants assumed the default AMAD values (1 μm for the old model and 5 μm for the new model) but also other AMAD values have been used. Table 4.3.7.3 and 4.3.7.4 show the geometric mean and standard deviation of intake and committed effective dose calculated with the old ICRP lung model using retention class Y parameters and with the new ICRP lung model using absorption type S parameters, respectively. As can be expected there is a significant dependence of the results on the AMAD values.

Tab. 4.3.7.3: Geometric mean and standard deviation of the best estimates (without outliers) of intake and committed effective dose based on the old ICRP lung model for retention class Y and different AMAD values

Particle size (µm AMAD)	Number of estimates	Intake (best estimate)		Committed effective dose (best estimate)	
		GM (kBq)	GSD	GM (mSv)	GSD
0.2	1	2	-	280	-
1	7	6.74	3.28	407	2.05
5	3	3.45	4.38	552	4.00
10	1	103	-	600	-

Tab. 4.3.7.4: Geometric (GM) mean and geometric standard deviation (GSD) of the best estimates (without outliers) of intake and committed effective dose based on the new ICRP lung model for absorption type S and different AMAD values

Particle size (µm AMAD)	Number of estimates	Intake (best estimate)		Committed effective dose (best estimate)	
		GM (kBq)	GSD	GM (mSv)	GSD
0.1	1	4.6		190	
1	2	4.47	2.28	72	2.28
5	7	24.4	2.94	309	1.70
10	1	80		410	

The distributions of the results are shown in Figs. 4.3.7.1 – 4.3.7.12, where Figs. 4.3.7.1 – 4.3.7.6 refer to the best estimate of the intake and Figs. 4.3.7.7 – Figs. 4.3.7.12 to the best estimate of the committed effective dose. As can be seen, the frequency distributions for the committed effective dose can be approximated much better by log-normal distributions than the frequency distributions for the intake. This is mainly due to the fact that the estimate of the intake is governed by the AMAD to a much higher extent than the estimate of the committed effective dose (see also Tables 4.3.7.3 and 4.3.7.4).

It is interesting to note that 11 out of 29 participants found the committed effective dose to be higher than the life-span dose of 400 mSv. So the dose assessment would have had in at least 38 % of the institutions dramatic consequences for the involved person (i.e. change of working place). These consequences, however, should depend on the real dose rather than on the method of dose assessment.

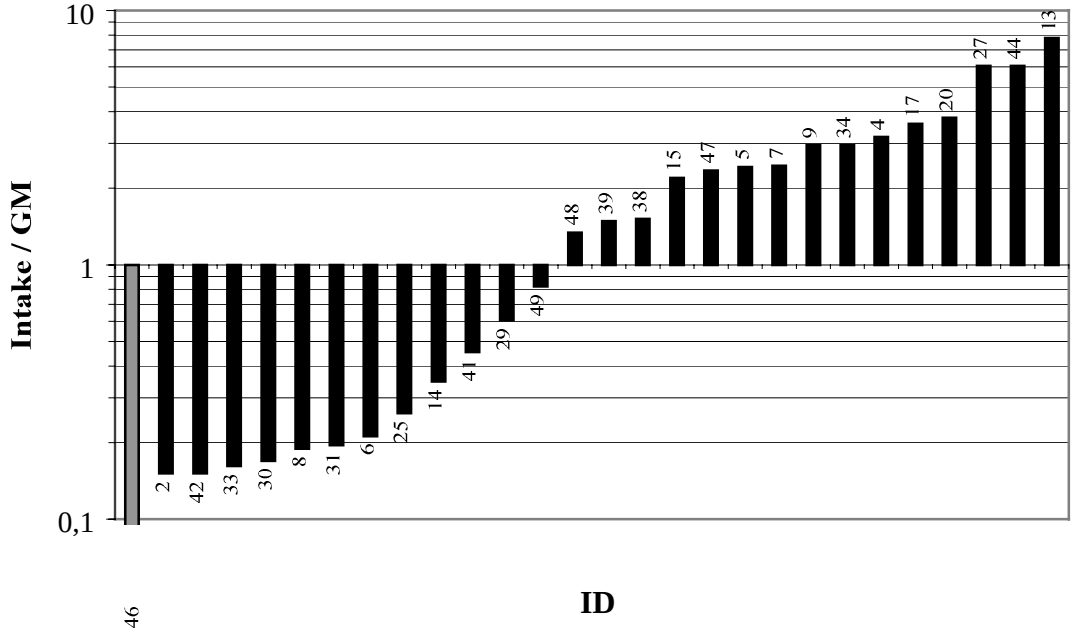


Fig. 4.3.7.1: Results of the individual participants (light bar: outlier): Intake normalised to the geometric mean (GM = 13.2 kBq; GSD = 3.8; 98.8 C.I. = 0.47 – 373 kBq)

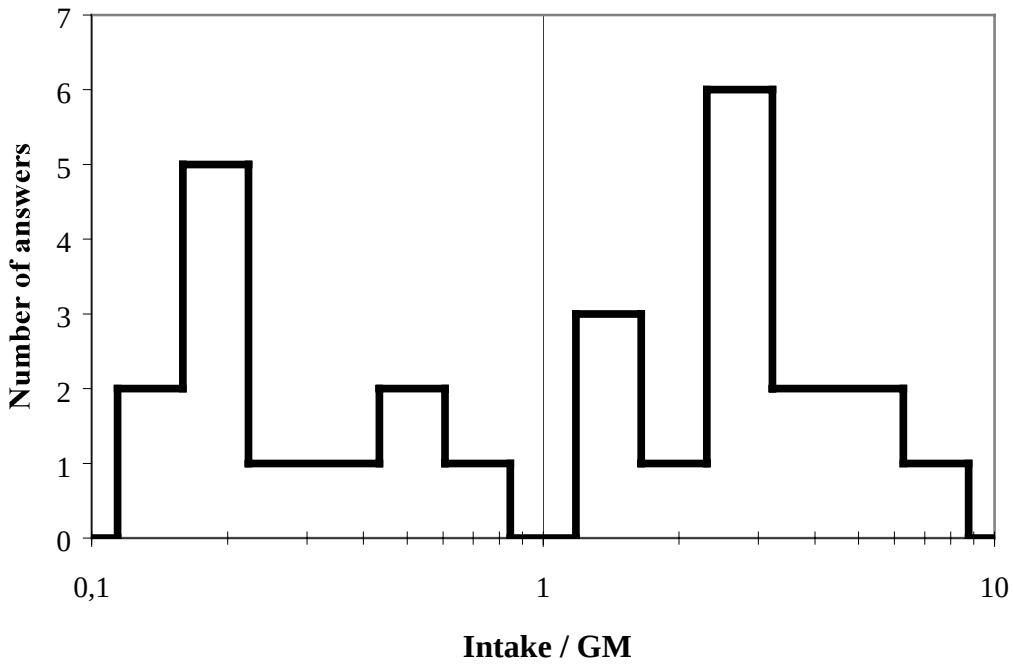


Fig. 4.3.7.2: Frequency distribution of the results: Intake normalised to the geometric mean (GM = 13.2 kBq; GSD = 3.8; 98.8 C.I. = 0.47 – 373 kBq)

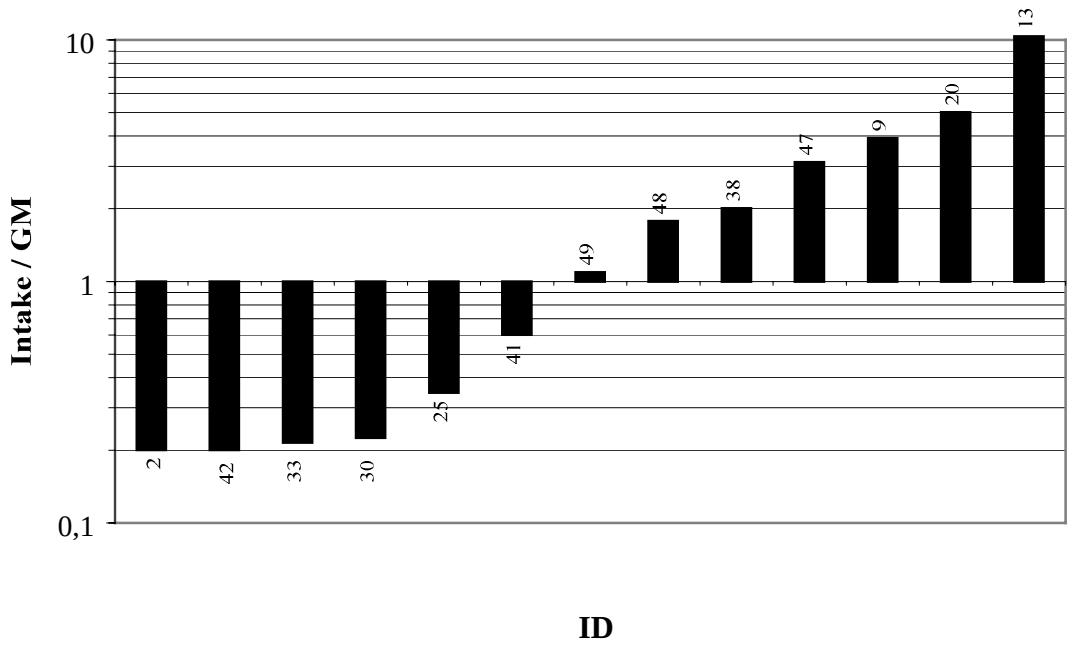


Fig. 4.3.7.3 Results of the individual participants using the old ICRP models: Intake normalised to the geometric mean (GM = 9.96 kBq; GSD = 4.01; 98.8 C.I. = 0.31 – 321 kBq)

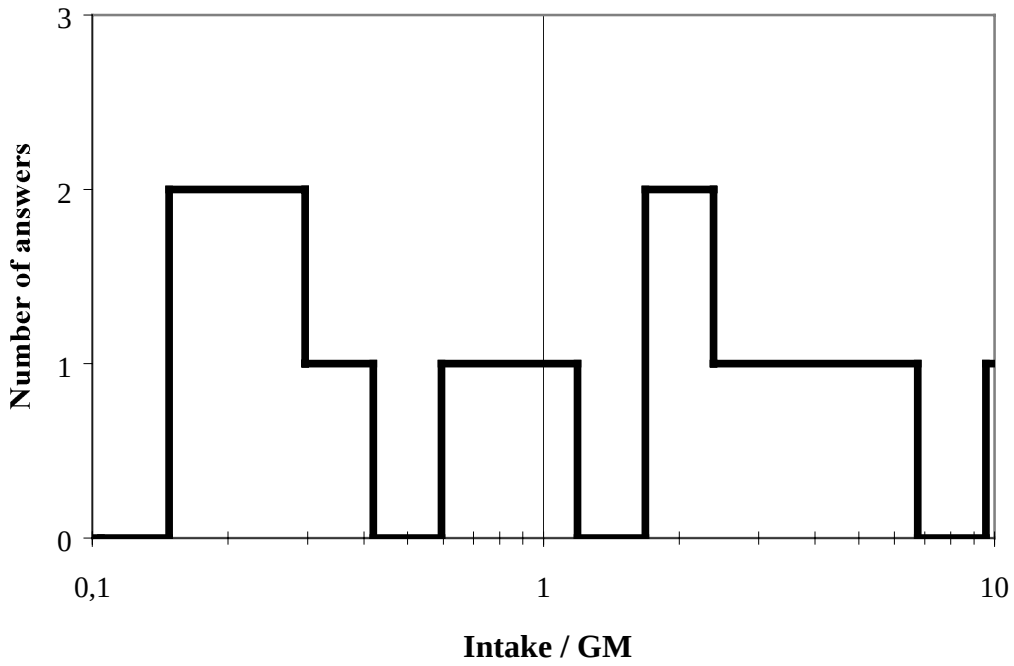


Fig. 4.3.7.4: Frequency distribution of the results based on the old ICRP models: Intake normalised to the geometric mean (GM = 9.96 kBq; GSD = 4.01; 98.8 C.I. = 0.31 – 321 kBq)

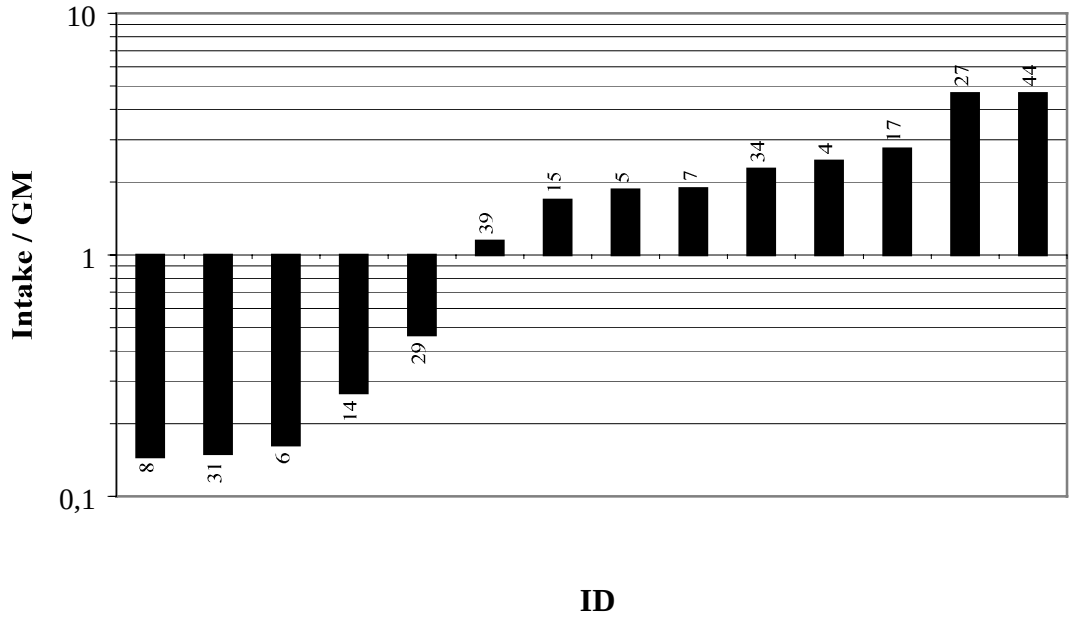


Fig. 4.3.7.5: Results of the participants using the new ICRP models: Intake normalised to the geometric mean (GM = 17.2 kBq; GSD = 3.59; 98.8 C.I. = 0.70 – 419 kBq)

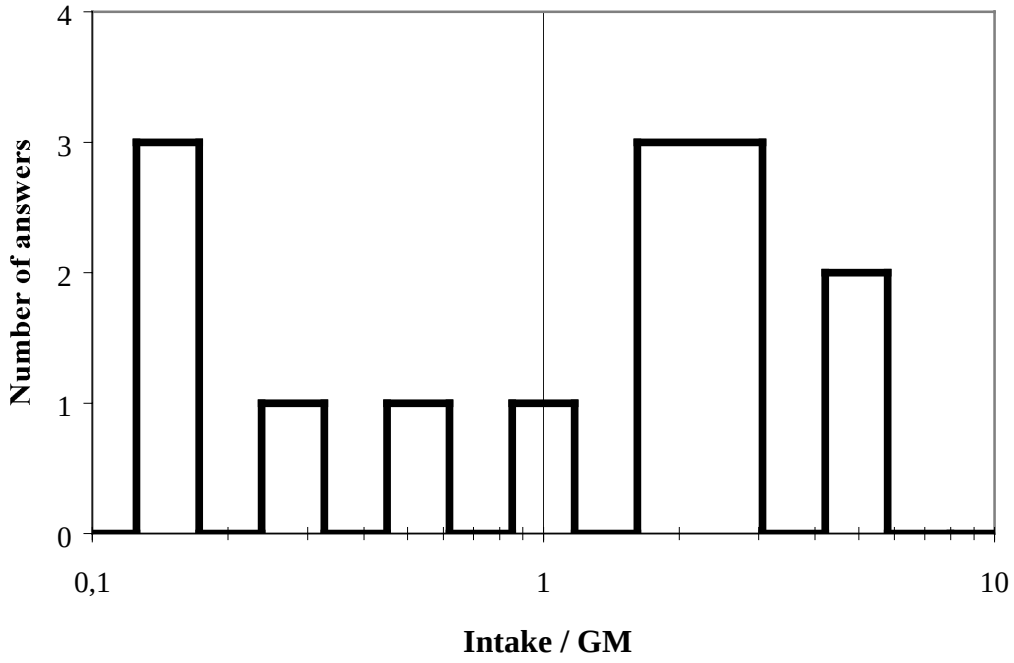


Fig. 4.3.7.6: Frequency distribution of the results based on the new ICRP models: Intake normalised to the geometric mean (GM = 17.2 kBq; GSD = 3.59; 98.8 C.I. = 0.70 – 419 kBq)

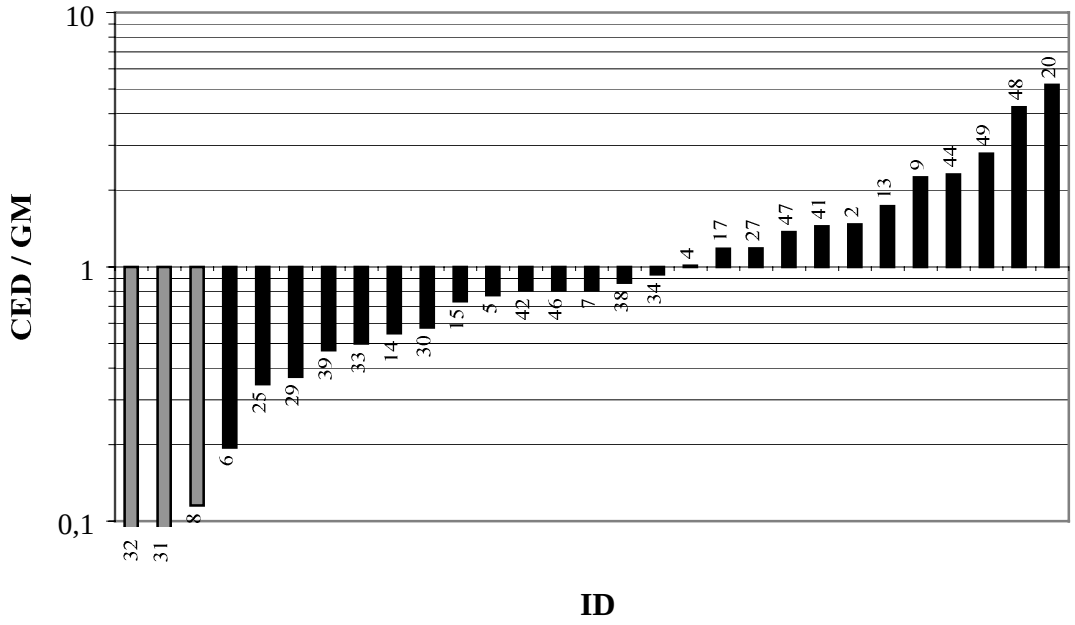


Fig. 4.3.7.7: Results of the individual participants (light bars: outliers): Committed effective dose normalised to the geometric mean (GM = 346 mSv; GSD = 2.16; 98.8 C.I. = 50.7 – 2370 mSv)

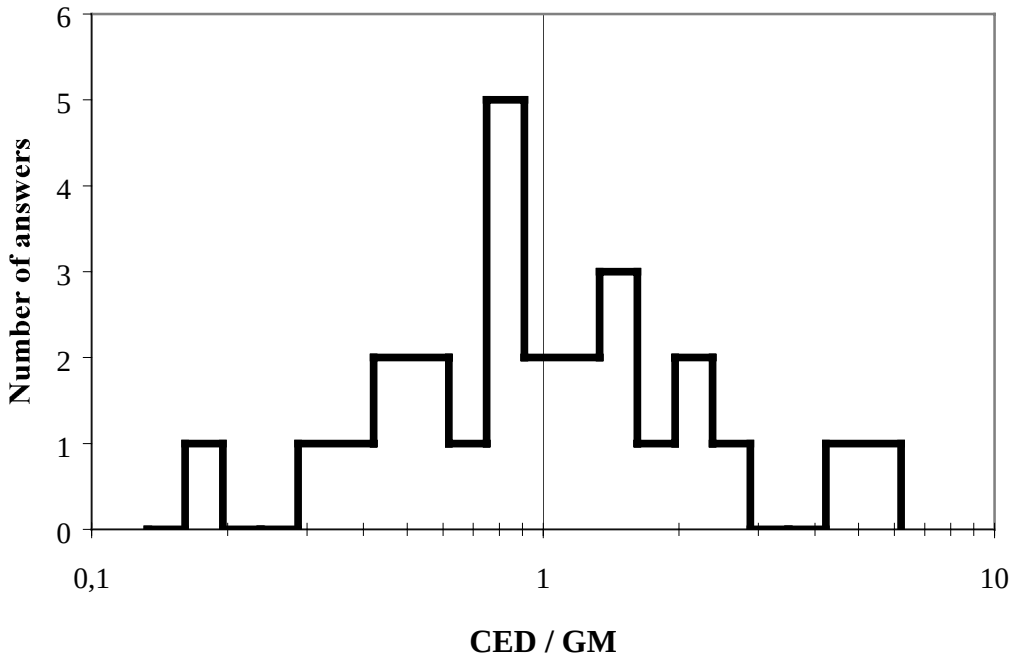


Fig. 4.3.7.8: Frequency distribution of the results: Committed effective dose normalised to the geometric mean (GM = 346 mSv; GSD = 2.16; 98.8 C.I. = 50.7 – 2370 mSv)

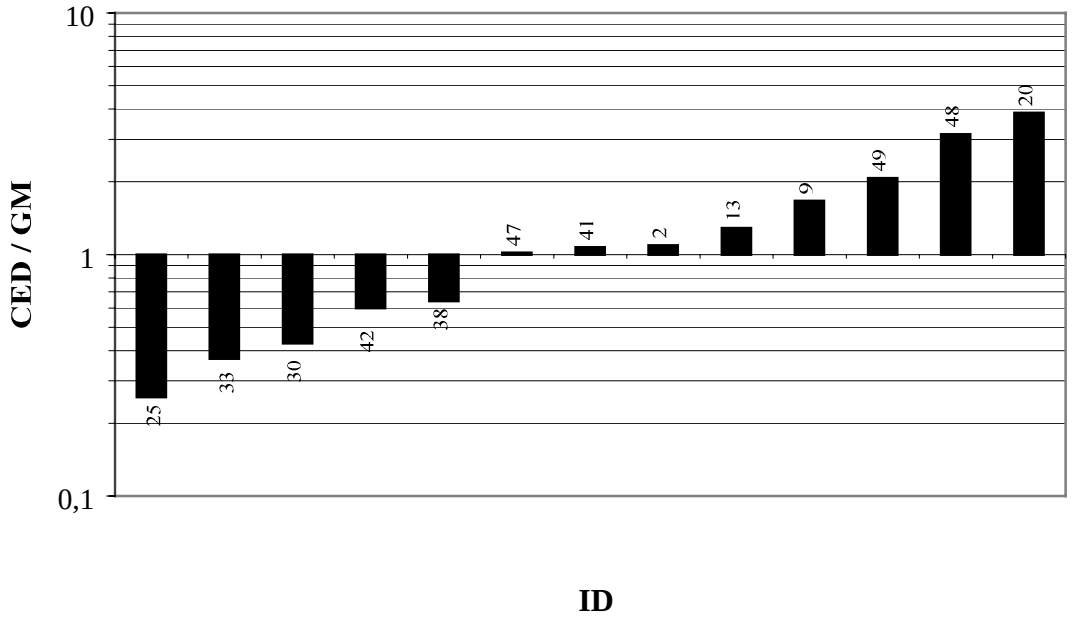


Fig. 4.3.7.9: Results of the individual participants using the old ICRP models: Committed effective dose normalised to the geometric mean (GM = 467 mSv; GSD = 2.27; 98.8 C.I. = 60.6 – 3602 mSv)

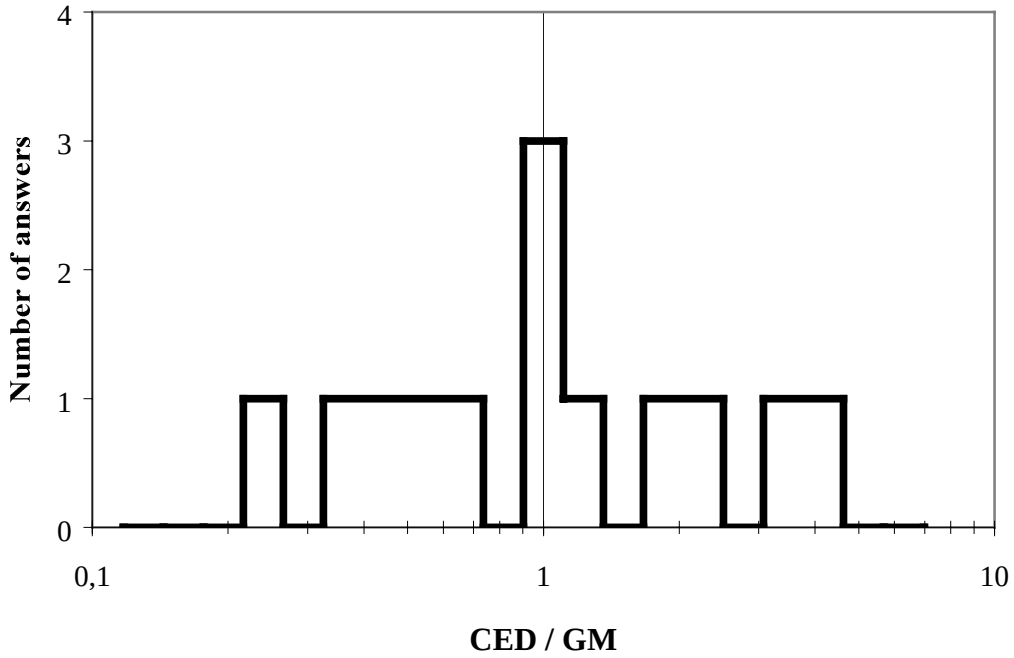


Fig. 4.3.7.10: Frequency distribution of the results based on the old ICRP models: Committed effective dose normalised to the geometric mean (GM = 467 mSv; GSD = 2.27; 98.8 C.I. = 60.6 – 3602 mSv)

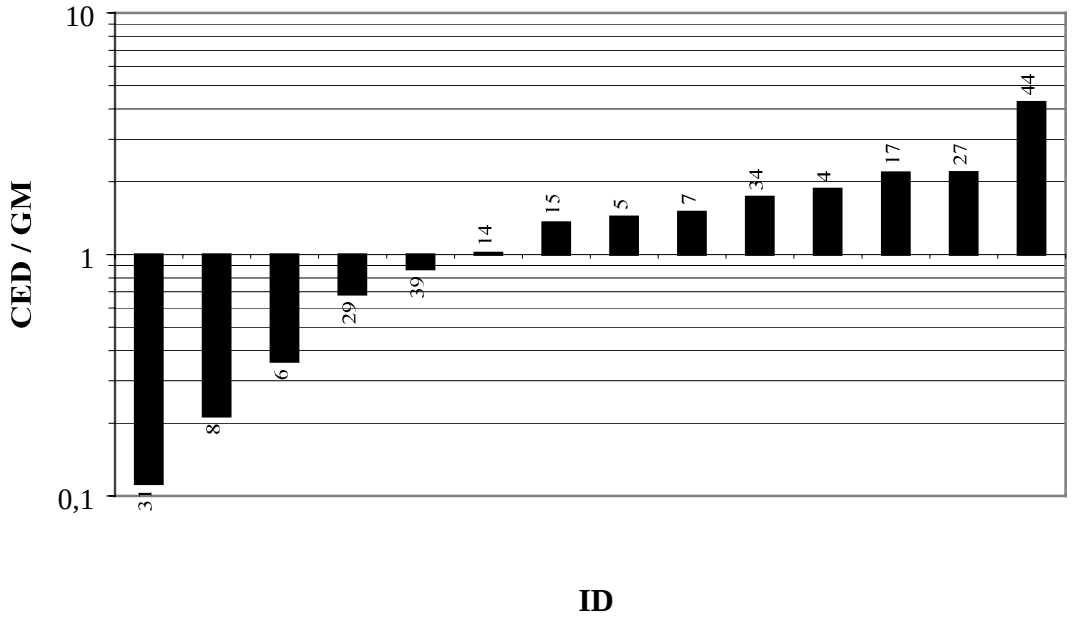


Fig. 4.3.7.11: Results of the participants using the new ICRP models: Committed effective dose normalised to the geometric mean (GM = 187 mSv; GSD = 2.70; 98.8 C.I. = 15.7 – 2234 mSv)

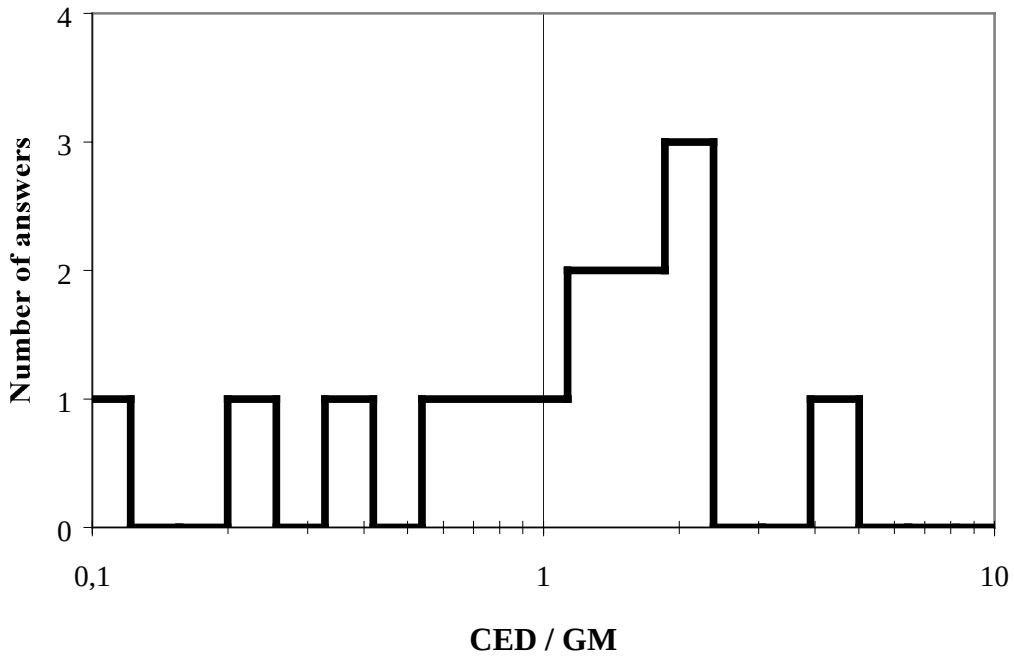


Fig. 4.3.7.12: Frequency distribution of the results based on the new ICRP models: Committed effective dose normalised to the geometric mean (GM = 187 mSv; GSD = 2.70; 98.8 C.I. = 15.7 – 2234 mSv)

Annex A: Programme schedule

Table A.1: Organisation of the Intercomparison Exercise

Time	Programme point	Meeting	Responsibility
March 97	Establishment of the Intercomparison Subgroup; preparation of time schedule	Action Group (Madrid)	M. Bailey
April/Aug. 97	Collecting materials for cases scenarios		Subgroup
1-5 September 97	Definition of objectives, guidelines and formats for the intercomarison; preparing cases scenarios	Subgroup (Bologna)	H. Doerfel
19 September 97	Presentation of the status of the organisation of the intercomparison to the Action Group	Action Group (Pierrelatte)	H. Doerfel
31 December 97	Deadline for application of participants		Participants
October 97 – February 98	Finalizing the case scenarios		Subgroup
16-20 Feb. 98	Establishing a database for the participant data; definition of the formats of the intercomparison materials	Subgroup (Höfen)	H. Doerfel
15 March 98	Distribution of case scenarios to participants		H. Doerfel
31 August 98	Deadline for submitting results by participants		Participants
7 October 98	Distribution of answers to Subgroup members		H. Doerfel
March-October 98	Establishing of a database for the intercomparison data		F. Stelzig
26-30 October 98	Review of the submitted results; compilation of the results for input in a uniform way into the database; input of the data; preparing the outline of the final report; discussion of the organisation of the workshop	Subgroup (Höfen)	H. Doerfel
2-3 November 98	Presentation of the status of the organisation of the intercomparison to the Action Group	Action Group (Höfen)	H. Doerfel
15 December 98	Distribution of a circulation asking the participants to check the database inputs and to provide additional information		H. Doerfel
15 January 99	Deadline for the participants to provide additional information		Participants

Table A.1 (continued): Organisation of the Intercomparison Exercise

Time	Programme point	Meeting	Responsibility
December 98 – January 99	Preparing the database outputs		F. Stelzig
8-12 February 99	Review of the additional information submitted by the participants; update of the database; preparation of updated database outputs; first look at the results; definition of the formats and contents of the final report; drafting the general parts of the final report; identifying participants for presenting their results at the workshop	Subgroup (Budapest)	A. Andrasi H. Doerfel
February – March 99	Analysis of the results; drafting the case specific chapters of the report; distribution of updated database outputs and the drafts of the report to the members of the Action Group; local organisation of the workshop		
22-26 March 99	Finalising the draft report	Subgroup (Bologna)	G. Tarroni H. Doerfel
25-26 March 99		Action Group (Bologna)	
9 April 99	Distribution of draft report to the participants		H. Doerfel
17-19 May 99	Workshop with the participants	Participants (Weimar)	H. Doerfel
20-21 May 99	Finalising the report	Subgroup (Weimar)	H. Doerfel

Annex B: Participating institutes

The organisation and scientific co-ordination of the intercomparison has been done by Research Centre Karlsruhe, Germany (H. Doerfel), KFKI Atomic Energy Research Institute Budapest, Hungary (A. Andrasi) and ENEA Institute for Radiation Protection Bologna, Italy (G. Tarroni, C.-M. Castellani).

Table B1: Participating institutions

Country	Institution (contact person)
Argentina	CAE, Buenos Aires (I. Gomez Parada)
Austria	Austrian Research Centre, Seibersdorf (F. Steger)
Belgium	AIB Vincotte Nucléaire, Bruxelles (J.-P. Culot)
Belgium	CEN/SCK, Mol (C. Hurtgen)
Belgium	Preventiedienst VRM (J. Van Dam)
Bulgaria	Kozloduy NPP (G. Valtchev, L. Dimitrov)
Canada	Radiation Protection Bureau, Ottawa (G. Kramer)
Canada	Ontario Hydro Nuclear (K. Thind)
Czech Republic	National Radiation Protection Institute, Prague (I. Malatova)
Denmark	Risö National Laboratory (B. Lauridsen)
Finland	Radiation and Nuclear Safety Authority - STUK, Helsinki (T. Rahola)
France	COGEMA – Etablissement de La Hague, Beaumont-Hague (P. Royer)
France	EDF – GDF Paris, (C. Chevalier)
France	IPSN, Fontenay-aux-Roses (P. Berard)
France	IPSN – DPHD, Fontenay-aux-Roses (B. LeGuen)
France	Ministere de la Defense, Clamart (P.-M. Curet)
Germany	BG Feinmechanik und Elektrotechnik, Köln (T. Ludwig)
Germany	Forschungszentrum Jülich, Jülich (D. Beyer)
Germany	Siemens AG, Hanau (R. Sommer-Ballat)
Hungary	Nat. Res. Inst. for Radiobiology & Radiohygiene, Budapest (A. Kerekes)

Table B1 (continued): Participating institutions

Country	Institution (contact person)
India	Indira Gandhi Centre for Atomic Research, Tamilnadu (V. Rajagopal)
Israel	IAEC Nuclear Research Centre Negev, Beer-Sheva (R. Kol)
Israel	SOREQ Nuclear Research Centre, Yavne (I. Silverman)
Italy	Azienda Ospedaliera di Careggi, Firenze (F. Rossi)
Italy	Azienda Ospedaliera Pisina, Pisa (A. Traino)
Italy	Arcispedale S.M.Nuova, Reggio-Emilia (L. Mondini)
Italy	Bufalini Hosp., Cesena (S. Lazzari, F. Del Dottore)
Italy	ENEA, Bologna (C.-M. Castellani)
Italy	ENEL S.p.A. SGN, Sessa Aurunca (S. Alfieri)
Italy	Inst. Ospitalieri di Cremona, Cremona (S. Magri)
Italy	Spedali Civili di Brescia, Brescia (M. Galelli)
Italy	Ospedale Maggiore, Bologna (G. Guidarelli)
Italy	Ospedale Mauriziano, Torino (P. Manzone)
Italy	Ospedale Niguarda Ca'Granda, Milano (G. Pedroli)
Italy	ARPAV – CRR, Verona (F. Predicatori)
Japan	Japan Atomic Energy Res. Inst. – Tokai-mura, Ibaraki, (H. Omura)
Norway	Institute for Energy Technology, Kjeller (T. Ramsoy)
Romania	Military Med. Scientific Res. Centre, Bucharest (N.M. Mocanu, M.A. Puscalau)
Russia	State Research Centre of Russia – Inst. of Biophysics, Moscow (A. Molokanov)
Slovenia	University Medical Centre, Ljubljana (M. Grmek)
Spain	CIEMAT, Madrid (A. Espinosa, M.A. Lopez)
Sweden	Studsvik Nuclear AB, Nyköping (P. Brandelind)
Sweden	Swedish Rad. Prot. Inst., Stockholm (M. Alvarez)

Table B1 (continued): Participating institutions

Country	Institution (contact person)
Ukraine	Ukrainian Rad. Prot. Inst., Kiev (V. Berkovski)
United Kingdom	AEA Technology, Dounreay (G. Roberts)
United Kingdom	AEA Technology, Harwell (R. Birch)
United Kingdom	AWE Aldermaston, Reading Berkshire (P. Stewart)
United Kingdom	British Nuclear Fuels, Sellafield (W. Battersby)
United Kingdom	DERA Rad. Prot. Services, Alverstoke (E. Cowling)
United Kingdom	NRPB, Chilton Didcot (A. Birchall)

Annex C: General structure of the cases

All cases were presented according to the following structure:

1. The event

   1.1 Description of the working area
   1.2 Characteristics of work
   1.3 Reasons for monitoring; initiating event
   1.4 Actions taken

2. Additional information

   2.1 Air monitoring
   2.2 Chemical form
   2.3 Physical characteristics, particle size
   2.4 Nose swab, bronchial slime or similar
   2.5 Non removable skin contamination
   2.6 Wound site activity
   2.7 Any intervention used (blocking, chelating, etc.)

3. Body monitoring data

   3.1 Organ activity measurement

Date	Organ content			
	Organ	Nuclide	Activity	Uncertainty

   3.2 Whole body activity measurement

Date	Whole body content		
	Nuclide	Activity	Uncertainty

3.3 Excretion monitoring data

3.3.1 Urine activity measurement

Sample				Daily excretion rate	
Date	Volume	Activity	Remarks	Activity	Uncertainty

3.3.2 Faeces activity measurement

Sample				Daily excretion rate	
Date	Volume	Activity	Remarks	Activity	Uncertainty

3.4 Personal Data

3.4.1 Sex
3.4.2 Age
3.4.3 Weight

4. Other comments relevant for intake and dose estimation

Annex D: Guidelines for presenting the results

The participant should provide answers for as many case scenarios as the participant prefers to handle. For a particular case scenario, if a participant obtains more than one answer using different approaches, all answers should be provided. The participant should also determine the best answer from all possible answers and indicate the basis for such determination.

The answers should be given according to the following scheme.

1. General information about the methods applied
   - 1.1 National guidelines (are there any, and if so, are they applied or not)
   - 1.2 Computer codes

2 Intake assumptions
   - 2.1 Mode of intake (single, multiple or chronic)
   - 2.2 Time of intake(s)
   - 2.3 Pathway of intake(s)

3. Model(s) applied
   - 3.1 Standard ICRP models
   - 3.2 Type of model(s)
   - 3.3 Model parameters (inhalation class or clearance type, particle size, f_1-value)
   - 3.4 Other models
     - 3.4.1 Reason for applying other models
     - 3.4.2 Type of model(s)
     - 3.4.3 Characteristic parameters

4. Data handling
   - 4.1 Data used for calculation (all or selected data)
   - 4.2 Method for handling of measurements below detection limit
   - 4.3 Method for assessment of uncertainty

5. Results (SI units)
   - 5.1 Intake(s)
   - 5.2 Dose (committed dose and, if relevant, also annual dose)
   - 5.3 Effective dose
   - 5.4 Organ dose(s) (for limiting organs only)

6. Additional information

Annex E: Computer codes used by the participants

The organisers decided to present the computer codes used by the participants not case by case but in a general way, since it is likely that a participant will use the same code for all cases. In some cases, calculations can be made by hand (ie using published tables of excretions or dose coefficients) or by common spresd sheet (MS Excell and Lotus have been cited). In general, however, it is reasonable to apply computer codes for (i) the calculation of retention or excretion functions, (ii) the evaluation of intake by fitting of the bioassay data and (iii) the calculation of dose coefficients. These computer codes allow the user to simulate various intake patterns in order to achieve optimum agreement of the fitted functions and the measured bioassay data.

The cited computer codes were collected into 3 families (Table E.1):

1. Commercial codes based on the old ICRP models (i.e. ICRP 30, 54 etc.)
2. Commercial codes based on the more recent ICRP models (i.e. ICRP 66, 67, etc).
3. In house codes developed by the user or his institution, respectively.

Table E1: Grouping of computer codes used by the participants

Commercial codes related to ICRP 30	Commercial codes related to the introduction of ICRP 66 model	In house codes
INDOS, CINDY, BAP,	LUDEP (Version 1.1 to 2.75)	MIDAS, SIDAS, IMBA
AGEDOS, GENMOD-PC		TRIT, CAESIUM, PLUTO
RETEX (?)		IAMB, SS115, IDSS 2.0
		IMIE 3.0, InDoS, ERC

Table E.2 lists the computer codes as cited by the individual participants. Some of the participants refer also to more general codes, such as Mathematica or MICROFIT , Mathcad, SAAM II. These codes being not related especially to internal dosimetry are not included in the tables. As can be seen from Table E.2, fifteen participants use LUDEP, wheras five participants use CINDY and two participants use RETEX. So LUDEP is the most widely used computer code, followed by CINDY and RETEX in a much smaller extend.

Table E2: Computer codes used by the individual participants

Participant ID	Code most used	Participant ID	Code most used
1	LUDEP 1.1	26	n.s.
2	In house	27	In house
3	None	28	IABM
4	LUDEP 2.05	29	IDSS, IMIE
5	LUDEP 2.75	30	CINDY
6	LUDEP 2.05	31	InDoS
7	LUDEP 2.04	32	LUDEP 2.05
8	None	33	LUDEP 2.05
9	CINDY	34	LUDEP 2.0
10	n.s.	35	In house
11	LUDEP	36	n.s.
12	n.s.	37	n.s.
13	LUDEP 2.0	38	AGEDOS
14	LUDEP 2.05	39	LUDEP 2.04
15	LUDEP 2.05	40	None
16	In house	41	CINDY
17	LUDEP 2.05	42	None
18	INDOS	43	None
19	CINDY	44	In house
20	CINDY	45	In house
21	LUDEP 2.04	46	GENMOD-PC
22	None	47	In house
23	RETEX	48	RETEX
24	In house	49	None
25	In house	50	n.s.

Annex F: Data on cases

F1: Continuous intake of Tritium

F1.1 Case description

Main characteristics

- Member of the public
- Real testing case
- Direct intake through intact skin
- Urine measurement
- Direct dose assessment from urine data

F1.1.1 The event

F1.1.1.1 *Description of the working area*
Not relevant

F1.1.1.2 *Characteristics of work*
Not relevant

F1.1.1.3 *Reasons for monitoring, initiating event*
In the course of incorporation monitoring elevated concentrations of Tritium in urine were found in some radiation workers who were not occupationally exposed to Tritium. Further investigation revealed the sources of contamination to be wrist watches with plastic cases containing luminous dials with Tritium.

F1.1.1.4 *Actions taken*
In an experiment a volunteer wore a watch with high Tritium emissions for 29 days. The average daily concentration of Tritium in urine was measured for a total of 50 days starting with the first day of exposure.

F1.1.2 Additional information

A1.1.2.1 *Air monitoring*
not applicable

F1.1.2.2 *Chemical form*
Unknown

F1.1.2.3 *Physical characteristics, particle size*
Unknown

F1.1.2.4 *Nose swab, bronchial slime or similar*
None

F1.1.2.5 *Skin contamination*
Not measured

F1.1.2.6 *Wound site activity*
None

F1.1.2.7 *Any intervention used (blocking, chelating, etc)*
None

F1.1.3. Personal data

F1.1.3.1 *Sex:* Male
F1.1.3.2 *Age:* 53 y
F1.1.3.3 *Weight:* 90 kg

F1.1.4 Body monitoring data

F1.1.4.1 *Whole body activity measurement*
none

F1.1.4.2 *Organ activity measurement*
none

F1.1.5. Excretion monitoring data

F1.1.5.1 *Urine activity measurement*

The results are given in the table below. The uncertainties are given in terms of 1 standard deviation

Days after beginning of intake	Daily average Tritium concentration in urine [Bq/l]	Days after beginning of intake	Daily average Tritium concentration in urine [Bq/l]
0	0	26	2928 ± 51
1	433 ± 26	27	2814 ± 51
2	576 ± 22	28	2868 ± 51
3	811 ± 22	29	3084 ± 53
4	971 ± 29	30	not measured
5	1316 ± 42	31	not measured
6	1458 ± 25	32	2150 ± 127
7	1721 ± 28	33	2090 ± 127
8	1755 ± 29	34	not measured
9	1923 ± 31	35	2060 ± 127
10	2185 ± 45	36	2070 ± 125
11	2339 ± 48	37	2020 ± 127
12	2404 ± 45	38	not measured
13	2537 ± 49	39	1410 ± 113
14	2617 ± 128	40	1250 ± 103
15	2873 ± 51	41	1160 ± 100
16	2972 ± 33	42	1030 ± 130
17	2964 ± 46	43	not measured
18	3100 ± 48	44	780 ± 90
19	2837 ± 44	45	890 ± 93
20	2921 ± 34	46	not measured
21	2843 ± 44	47	700 ± 90
22	2783 ± 35	48	620 ± 87
23	2877 ± 48	49	580 ± 87
24	2889 ± 55	50	450 ± 87
25	2855 ±54		

F1.1.5.2 Fecal activity measurement
None

F1.1.6 Other comments relevant for intake and dose calculation

It has to be assumed that the Tritium enters the body via the skin.

F1.1.7 Form of results

Average daily intake [Bq]	Average daily effective dose rate during equilibrium [μSv]	Committed effective dose E(50) due to total intake [μSv]

Additional comments

F1.1.7.1 Computer code(s) applied
F1.1.7.2 Model(s) applied
F1.1.7.2.1 Standard ICRP models
A1.1.7.2.1.1 Type of models
A1.1.7.2.1.2 Model parameters (inhalation class or clearance type, AMAD etc.)
F1.1.7.2.2 Other models
A1.1.7.2.2.1 Reason for applying other models
A1.1.7.2.2.2 Type of models
A1.1.7.2.2.3 Characteristical parameters
F1.1.7.3 Data used for calculation (all data or selected data)
F1.1.7.4 Additional information

F1.2 Answers of the participants

Table F1.2.1:Results (outliers in shadow)

Participant ID	Daily intake (kBq/day)	Daily effective dose (μSv/day)	Committed effective dose (μSv)
1	10850	0.16	5.43
2	13000	0.16	5.4
3	11700	0.18	6.1
4	16000	0.22	6.3
5	10000	0.14	5.2
6	11400	0.11	4.58
7	10400	0.2	2.7
9	11000	0.14	4.2
10	11400	0.194	5.4
11	4300	0.08	2
12	8850	0.12	4.62
13	9300	0.15	5.2

Table F1.2.1 (continued):Results (outliers in shadow)

Participant ID	Daily intake (kBq/day)	Daily effective dose (μSv/day)	Committed effective dose (μSv)
14	20300	0.2	5.8
15	11930	0.2	5.8
16	13828	0.208	7.22
17	18500	0.15	4.7
18	6369	0.189	8.4
19	12000	0.08	6.2
20	11000	0.187	5.4
21	14000	0.15	4.9
23	10900	0.25	5.5
25	11000	0.2	5.7
28	8711	0.011	4.55
29	8700	0.11	4.6
30	11000	0.19	5.5
33	17280	0.183	5.31
34	11700	0.2	5.85
35	17400	0.062	9.1
37	12400	0.2	6.5
38	9040	0.15	4.2
39	106	0.0045	0.139
41	13000	0.15	4.9
42	9091	0.155	4.48
43	19500	0.26	7.5
44	14000	0.18	5.6
45	20354	0.346	10.03
46	13983	0.153	4.45
47	10000	0.14	4.15
49	20500	0.3	10.7
GM	12236	0.170	5.29
GSD	1.320	1.362	1.163
AM	12713	0.177	5.351
ASD	3678	0.054	0.831
Minimum	106	0.0045	0.139
Maximum	20500	0.346	10.7

Table F1.2.2:Models applied

Participant ID	Type of models	Model parameters
1	n.s.	n.s.
2	ICRP30 (modified)	Tritiated water; T(1/2) modified to 8 d
3	ICRP30 (SEE); ICRP54; ICRP68 (Ing. dose coeff.)	Tritiated water
4	ICRP54	T(1/2) 8.35 d (derived from decay after 29 d); body water content 54 l due to 90 kg body weight
5	ICRP67 (biokinetics); ICRP60 (tissue weighting factors)	F1=1, body water content 42l (ICRP23)
6	ICRP30 (biokinetics); ICRP68 (modified dose factor)	Tritiated water
7	ICRP 72 (dose coefficient)	n.s
9	ICRP30	HTO
10	ICRP54	Tritiated water
11	ICRP54; ICRP78	T(1/2)=7.85 d derived from decay after 29 d, HTO
12	ICRP30 (SEE); ICRP54 (biokinetics; intake calculation); ICRP68 (dose coefficient);	n.s.
13	ICRP30	n.s.
14	HTO model from ICRP	T(1/2) = 5.7 d for better fitting
15	ICRP 30	T(1/2) = 8.8 d
16	ICRP54 (biokinetics); ICRP71 (dose coefficients)	T(1/2) = 9.4 d
17	ICRP30 modified	T(1/2) = 6.5 d
18	ICRP30	Biological T(1/2) = 6 d
19	ICRP30; Johnson HAT lung model	Tritiated water
20	Johnson HAT lung model	Tritiated water
21	n.s.	T(1/2) = 8.7 d (derived from the excretion after exposure)
23	ICRP30	HTO
24	ICRP30 (biokinetics); HTO vapour	n.s.
25	ICRP30 (biokinetics)	n.s.
28	ICRP54	f1=1; absorption type F or V, resp.; T(1/2)=10d
29	n.s.	T(1/2) = 7.9 d (from excretion after exposure)
30	ICRP30	f1=1
31	ICRP67 (biokinetics); ICRP71 (dose coefficient)	T(1/2) = 10 d (90%, HTO) and 40 d (10%, organic bound)
33	ICRP30; ICRP54	T(1/2) = 8 d
34	ICRP71, ICRP 54	T(1/2) = 10 d (ICRP 54)
35	ICRP30; ICRP54; ICRP68 (dose coefficients)	Biological T(1/2) = 9.7 d, Tritiated water
37	n.s.	n.s.
38	ICRP54 (biokinetics); ICRP56 (dose coefficient)	HTO
39	ICRP 56/68/78/71, HTO	T(1/2) = 7.9 d

Table F1.2.2 (continued).:Models applied

Participant ID	Type of models	Model parameters
41	ICRP30	n.s.
42	ICRP54	T(1/2) = 10 d
43	ICRP54 (dose coefficient corrected for body weight)	T(1/2) = 6 d (from increase) and 8.3 d (from decrease)
44	ICRP30; ICRP56	T(1/2) = 8.7 d (HTO)
45	ICRP54 (biokinetics); ICRP54 (dose coefficient)	n.s.
46	Intake through skin with hold-up in the skin likely, 2 compartment linear chain without recycling	T(1/2) = 0.05 d (skin) and 7.8 d (HTO)
47	ICRP30; ICRP54	ICRP 30, Tritiated water
49	ICRP30, ICRP68 and ICRP71 for dose coefficients	all soft tissue volume for the given subject = 81 l

Table F1.2.3:Data handling and additional information

Participant ID	Data used	Additional information
1	all	MIDAS and SIDAS are based on IRF equations for urine
2	all	Biological T(1/2) modified from 10 (ICRP30) to 8 d based on best fit to data, this having influence only on the intake but not on the dose
3	n.s.	
4	all	
5	all	Intake calculated by integration, SEE value calculated according to LUDEP 2.75
6	all	Calculation of average daily intake according to Piechowski et.al; SEE value according to LUDEP considering the body weight; dose coeff. From ICRP68 modified for body weight
7	all	Intake calculated as 200% of daily urinary excretion during equilibrium from 16 d to 29 d; dose factor according to ICRP72 (ingestion with f1=1)
9	all	Percutaneous uptake; calculation modified for 90 kg body weight
10	all	Deconvolution aproach
11	first 29 days	LUDEP 2.05
12	all	
13	all	
14	first 29 days	Dose coefficient calculated according to LUDEP 2.05
15	all	From the excretion rate it can be seen, that the watch was not worn in day 19 and thereafter in a different way; thus two different intake rates have been derived (13000 Bq/d for the first 18 days and then 10000 Bq/d for 10 days);
16	From day 18 to 29	For calculation of the average body activity during equilibrium

Table F1.2.3(continued): Data handling and additional information

Participant ID	Data used	Additional information
17	first 29 days	SEE and dose values considering the weight of the subject; the average daily dose refers to the soft tissue dose rather than to the effective dose
18	all	Biological halflife was set T(1/2) = 6 d according to the experiences on Indian reactor workers
19	all	
20	all	Second approach (B): Manual evaluation of data with ICRP30 standard values resulting in: average daily intake 11700 Bq/d; daily effective dose 0.2 uSv; committed effective dose 5.8 uSv
21	n.s.	For total body water calculation water balance and body weight of 90 kg was considered;
23	n.s.	For calculation of total body water and water balance a body weight of 90 kg was considered;
24	excretion during expos.	Dose calculated from ICRP30 dose coefficients
25	all	
28	data from day 19 to day 28	For calculation of daily intake and committed effective dose the excretion values of the first 29 days and for calculation of daily effective dose the values from 19 - 28 days were used
29	all	
30	all	For calculation of daily effective dose rate during equilibrium the report ECN-116 has been used
31	n.s.	The InDoS code is based on ICRP66 and can use different biokinetic models for the calculation of retention and excretion functions; however, it cannot be used for the calculation of the average daily effective dose
33	all	Intake and committed dose have been calculated considering the body weight
34	first 29 days	Alternative approach (50 l body water): Average daily intake 14000 Bq/d; average daily effective dose 0.24 uSv; committed effective dose 7.01 uSv
35	all	For estimation of daily effective dose rate NCRP 84 has been used
37	n.s.	
38	all	
39	all	GENMOD PC
41	equilibrium excr. 2900 Bq/l	Calculation of intake considering body weight
42	all	No correction for body weight applied
43	n.s.	Calculation have been performed both for T(1/2) = 6 d (from increase) and 8.3 d (from decrease), and results have been averaged
44	n.s.	Calculation of SEE using SEECAL 2.0
45	all	Calculation based on multiple intakes in the middle of each day during exposure
46	all	Alternative approach: Average daily intake 13000 Bq/d; average daily effective dose 0.17 uSv; committed effective dose 5.9 uSv
47	n.s.	
49	all	Two approaches were used to calculate the average daily intake. Method A via integration of the number of disintegration (trapez-rule); Method B via intake.

F1.3 Example I

Assessed by: *I. Malátová and I. Cešpírová, National Radiation Protection Institute, Prague, Czech Republic*

Introduction

The information provided for this case was that it was member of public who agreed to collect his daily urine as to enable to perform study in which intake from his wrist watches with plastic case containing luminous dials with Tritium would be studied. He wore the wrist watch during 29 days, afterwards, he ceased to use the wrist watch and measurement of volume activity in the urine went on.

There were given information about the individual that he is a male of the age 53 years and his weight was 90 kg. Volume activity in 44 samples of urine was given.

Tritium characteristics

Tritium is a pure beta emitter with an average energy of beta particles 5,7keV. Models describe behaviour of tritium in human body as tritiated water (HTO) and as organically bound tritium. For HTO it is assumed that 97% of activity equilibrates with the body water and it is retained with a half–time of 10 days. The remaining 3% is assumed to be incorporated into organic molecules and retained with half- time of 40 days.

In ICRP Recommendations and in Basic Safety Standards, there are given dose coefficients (dose per unit intake) for inhalation and ingestion of HTO; there is not given dose coefficient for the input through the skin. However, after the intake, HTO is very quickly distributed into the body water, so it is possible to describe human body as one compartment system (when OBT fraction is neglected). It follows also from the fact, that the dose coefficients for inhalation and ingestion are identical, that it is possible to use the same coefficient for the input through skin too.

Procedure used for the intake and dose calculation

The individual, for whom experimental data were given in the scenario, is described as to his body weight. As there are not enough data for the description of his metabolism (total excretion of water per day or total intake of water per day), there were used data for Reference Man as the first approximation.

Assumption used:

- Total body water in human body: 42 l
- Biological half- time of HTO in the human body: 10 days
- The activity of Tritium in the urine is in equilibrium with the activity of tritium in body water
- Organically bound tritium is neglected

In the figure F1.3.1, there is a graph of time course of the volume activity in excreted urine given in the scenario and in figure F1.3.2, the values of volume activity of tritium in urine are multiplied by 42l, giving thus retention of tritium in the body.

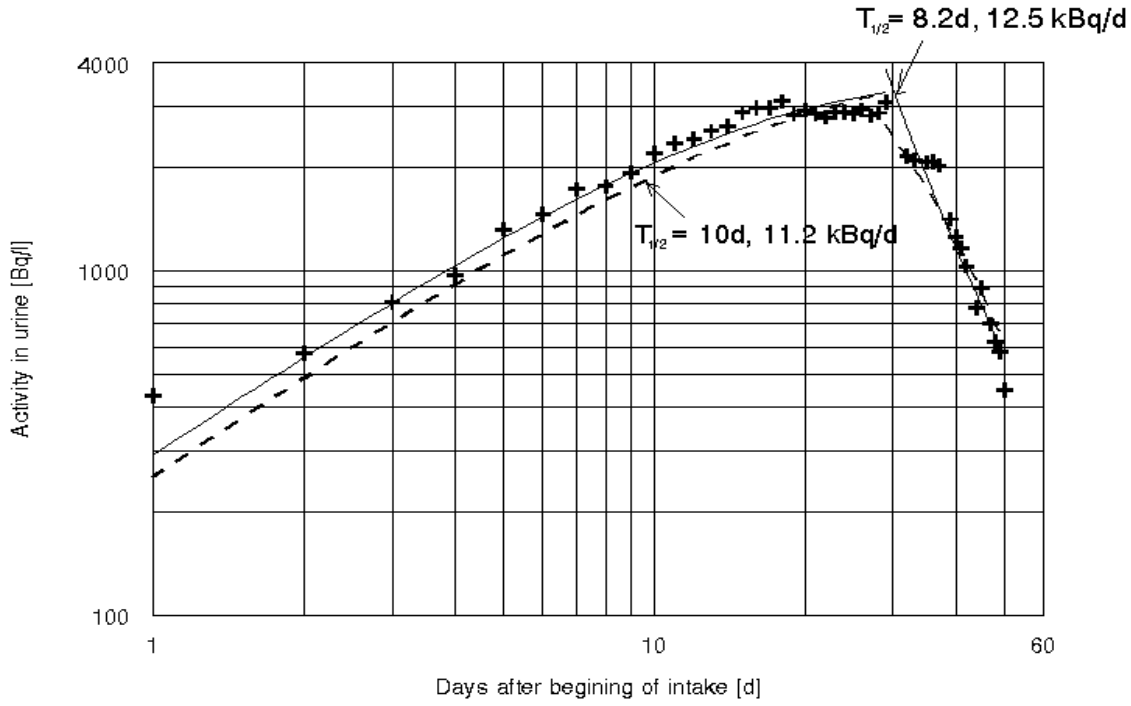


Fig. F1.3.1: Tritium activity in urine as function of time after beginning of intake

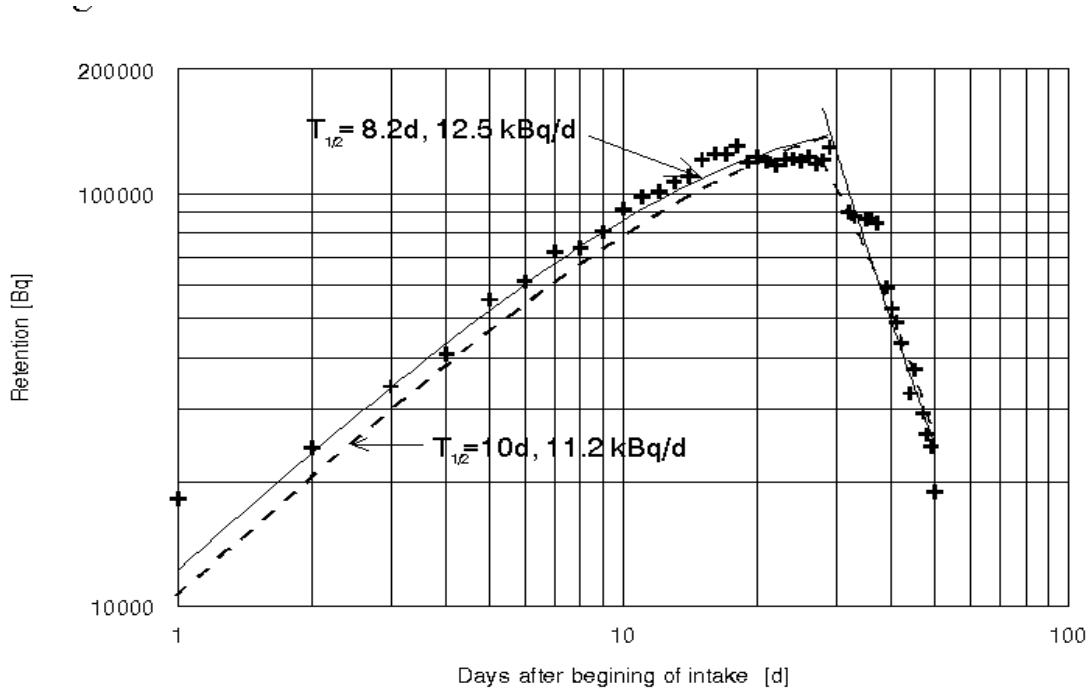


Fig. F1.3.2: Tritium retention as function of time after beginning of intake

The experimental values multiplied by 42 in figure F1.3.2 are fitted by two curves:

The first one representing the time for which continuous intake was going on (i.e. the day 1 to 29). It is fitted by the curve

$$R(t) = \frac{a}{\lambda_{ef}} \cdot \left[1 - \exp(-\lambda_{ef} \cdot t)\right] \qquad (1)$$

where
- *R(t)* is retention in the body [Bq]
- *a* is daily intake [Bq / d]
- λ_{ef} is effective decay constant , $\lambda_{ef} = \ln 2 / T_{ef}$ [d^{-1}]
- T_{ef} is effective half – time [d]
- *t* is time since intake
- $\lambda_{ef} = \lambda_{biol} + \lambda_{fyz}$

The second curve is fitted through points representing the days after the intake ceased. i.e. after the 29th day to the 50th day and it is expressed as a single exponential term

$$R(t) = A \cdot \left[\exp(-\lambda_{ef} \cdot t)\right] \qquad (2)$$

where
- *R(t)* is retention of tritium in the body [Bq]
- *A* is activity in the body in the day 29 [Bq]
- *t* is time since the intake stopped [d]
- λ_{ef} is effective decay constant [d^{-1}]

The daily intake, total intake and committed effective dose were calculated using parameters for Reference Man and also using calculated half–time from the experimental data.

Dose coefficient from Basic Safety Standards h = 1.8 x 10^{-11}[Sv/Bq] was used for calculation of committed effective dose..

Calculation of the energy e per 1 decay

Energy ***e*** per 1 decay is calculated using dose coefficient from IBSS (committed effective dose per 1Bq ingested or inhaled)

$$h_{ing} = 1.8 \cdot 10^{-11} \, Sv / Bq$$

Energy ***e*** per one decay is calculated from the formula

$$e = \frac{h_{ing}}{\int_0^{\infty} R(t)dt} \qquad (3)$$

where $\int_0^\infty R(t)dt$ is integral of the retention function in the human body per 1Bq intake

and it is:

$$\int_0^\infty R(t)dt = \int_0^\infty \exp[-\lambda_{ef} \cdot t]dt = \frac{1}{\lambda_{ef}} \quad (4)$$

Using parameters for Reference Man, $\boldsymbol{e} = 1{,}8 \times 10^{-11} \times 8{,}02 \times 10^{-7} = 14{,}5 \times 10^{-18}$[J/kg].

Results

Method 1

The daily intake was calculated by fitting the curve 1, using effective half–time 10 days. Committed effective dose was calculated from total intake, multiplied by ***e***.

From the figure F1.3.1 and F1.3.2 it follows that the equilibrium in the body (constant volume activity in the urine) is about 16 days (day 13 to day 29). The average volume activity is 2.9 kBq/l, multiplied by 42, retention in the body during equilibrium is 121.8 kBq. Number of decayed atoms per one day is: 121 800 × 24 × 3600 = 1.05 x 10^{10}, by multiplying this number by ***e*** average daily effective dose rate is 0.153μSv.

Daily intake	a = 11.2 kBq/d
Total intake	a_{tot} = 324.8 kBq
Committed effective dose	E(50) = 5.8 μSv
Average daily effective dose	D = 0.153μ Sv

Method 2

From the second part of the retention curve effective half- time for the contaminated person was calculated. It was found to be 8.2 days. Using this half–time, following values were found:

Daily intake	a = 12.5 kBq/d
Total intake	a_{tot} = 362.5 kBq
Committed effective dose	E(50) = 6.5μSv

It has to have in mind that dose coefficient **h** for Reference Man was used and that the effective half –life was calculated from volume activity in urine only. There are excreted water trough faeces and sweat too.

Average daily effective dose was calculated in the same way as in method 1.

Method 3

It is possible to use the same approach for the calculation of committed effective dose as for the calculation of average daily effective dose. This approach is very simple and needs only a calculator:

Sum of excreted amount of ^{3}H: 97 544 [Bq/l]

As urine activity is in equilibrium with body activity, then integral of decayed activity:

$$97\,544 \times 42 \times 24 \times 3600 = 3.54 \times 10^{11} \text{ decays}$$

Absorbed energy per 1 decay: 14.5×10^{-18} [J/kg]

Calculation of total energy absorbed:

$$14.5 \times 10^{-18} \times 3.54 \times 10^{11} = 5.13 \times 10^{-6} \text{ [Sv]} \quad (5.13 \text{ μSv})$$

to this value has to be included „tail“ caused by presence of ^{3}H after the measurement of excretion was finished – by the same procedure it is 0.338 μSv

Total committed effective dose :	5.47 μSv
Total intake:	5.47 μSv/ $1{,}8.10^{-11}$Sv/Bq = 303 900 kBq.
Daily average intake	303 900/29 = 10 479 Bq

The small difference between different approaches are in the different way of smoothing retention curve in the Method 1 and in Method 3 by interpolation for the days in which activity in urine was not measured. In method 2 there were used both person specific and Reference Man parameters

Table F1.3.1: Summary of the results of different approaches

		Method 1	Method 2	Method 3
Daily Intake	[kBq/d]	11.2	12.5	10.5
Total Intake	[kBq]	324.8	362.5	303.9
CED E (50)	[μSv]	5.8	6.5	5.5
AD CED	[μSv/d]	0.15	0.15	0.15

Average daily effective dose rate during equilibrium was calculated by the same method, therefore all the values are the same.

By expert judgement, following best estimate is:

Daily Intake:	11 kBq
Committed Effective Dose:	5.7 μSv
Average daily CED during equilibrium:	0.15 μSv

F1.4 Example II

Assessed by: *T. Ludwig, Institute for Radiation Protection of the professional association of the chemical industry and the professional association of the electrical and precision engineering industries*

Basic assumption

The Tritium in the watch has the chemical form of HTO. It escapes out of the watch case in form of HTO.

1st step: calculation of equilibrium activity

The fraction of water in relation to body mass of reference man is 60 %. The mass of person in case one is 90 kg. Therefore the total body water mass is 54 kg (see ICRP 23, page 280/281).

Assumption: the path of entering the body doesn‘t play a role, because tritiated water is completely and instantaneously absorbed and rapidly mixed with total body water. The retention R(t) as function of time of tritiated water can be approximately described by:

$$R(t) = A_0 \cdot \exp\left(-\frac{\ln 2 \cdot t}{\tau}\right)$$

where A_0 is the urine activity concentration at time zero and τ is the biological half-time (see ICRP 54, page 29)

Fig. F1.4.1 shows the urine activity concentration as function of time. From day one to approximately day 16 there is an increase of the concentration of tritium in urine. Between day 16 and day 29 there is an equilibrium situation between intake and excretion. After day 29 the concentration decrease, following an exponential drop described by the equation above with A_0 as average urine activity concentration during equilibrium.

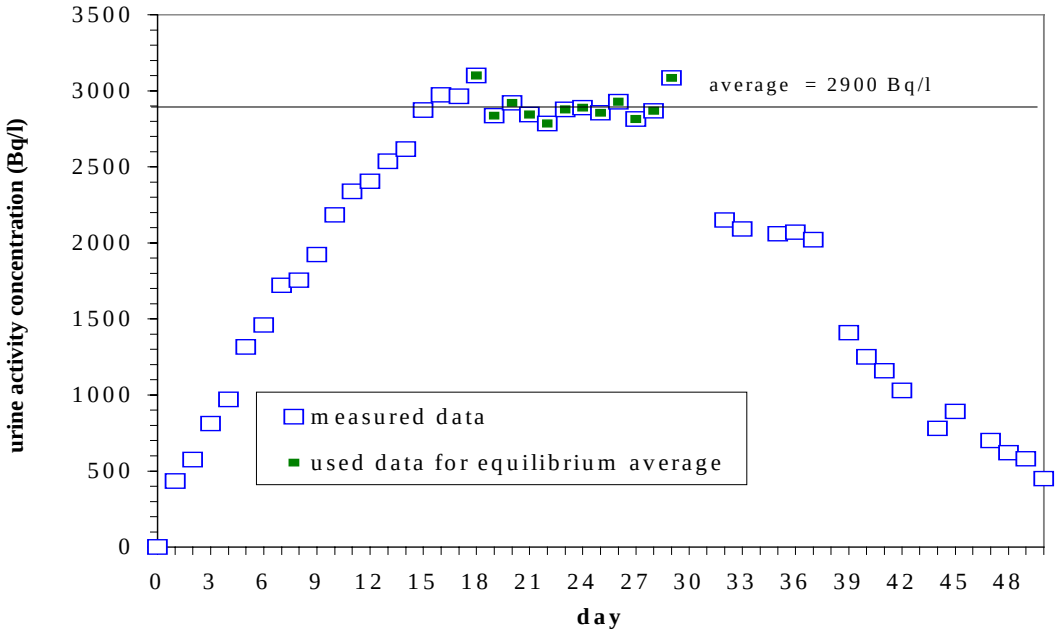


Fig. F1.4.1: Urine activity concentration vs. days after beginning of wearing the watch

To evaluate the average value of urine activity concentration during equilibrium, we only use the data from day 18 to day 29. The calculated average is 2,900 Bq/l.

The activity concentration in urine is the same as in total body water (ICRP 54, page 29). So the total body burden activity during equilibrium situation is:

$$2{,}900\ \text{Bq/l} \bullet 54\ \text{l} = \underline{156{,}600\ \text{Bq}}.$$

2nd step: evaluation of the biological half-time

The urine excretion at day 29 is set to 2,900 Bq/l. From the measured urine activity concentrations between day 30 and 50 one could evaluate the effective half-time by chi-square-fit, using the measured data and the following equation:

$$R(t) = 2{,}9\text{kBq/l} \cdot \exp\left(-\frac{\ln 2 \cdot (t - 29\text{d})}{\tau}\right)$$

Fig. F1.4.2 shows the fit in comparison to the measured data. The squares are the measured data, the triangles with the fit are the calculated values. The chi-square-fit gives a value of 9.4 days for the biological half-time τ.

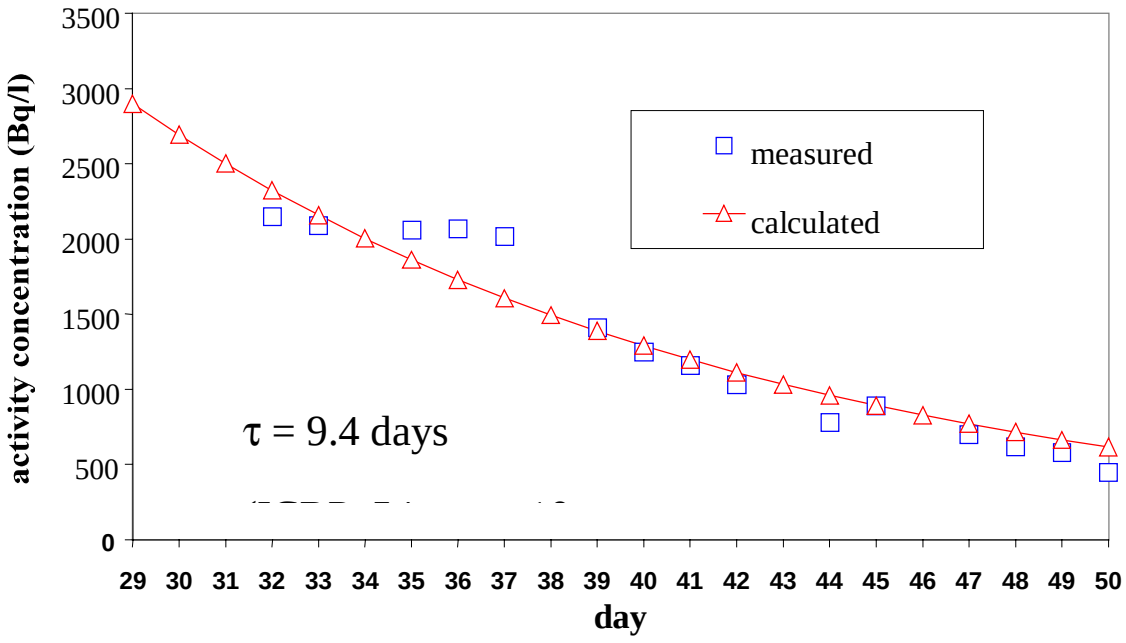


Fig. F1.4.2: Urine activity concentration vs. time after day 29

3rd step: evaluation of the average daily intake

The intake at day one is the urine activity concentration times the total body water mass:

433 Bq/l • 54 l = 23,382 Bq. The remaining activity at day two, calculated with τ = 9.4 days is: 21,719 Bq. The body burden activity at day two is : 576 Bq/l • 54 l = 31,104 Bq. The difference between the underlined values is the intake on day two: 31,104 Bq - 21,719 Bq = 9,384 Bq. The same calculation has to be done for each day. The sum of daily intakes from day 2 to day 29, divided by 28 days gives an average daily intake of 13,828 Bq. The value of day one has not been taken into account, because we think that this value has a great uncertainty.

(nota bene: this means a daily loss of body water of 4.8 l; the ICRP-publication no. 23 gives a value of only 3 l per day)

4th step: average daily effective dose rate during equilibrium

In this case, there is an easy way to calculate the dose rate. The total body burden activity during equilibrium situation has been calculated above, it is 156,600 Bq. The Committed Dose Equivalent (H_{50}) for such an intake has to be evaluate by multiplying this value with the right dose coefficient. With a biological half-time of 9.4 days it is a good assumption that the activity is constant in the first minute. So the question is, what ratio (x) of the Committed Dose Equivalent (H_{50}) is relevant in the first minute? This is the ratio of the belonging integrals of the dose rate as function of time:

$$X = \frac{\int_0^{1min} \dot{H}(t)dt}{\int_0^{50a} \dot{H}(t)dt} = \frac{\int_0^{1min} \exp\left(-\frac{\ln 2 \cdot t}{\tau}\right)dt}{\int_0^{50a} \exp\left(-\frac{\ln 2 \cdot t}{\tau}\right)dt} = 5.12 \cdot 10^{-5}$$

The dose coefficient for HTO is 1.8 • 10^{-11} Sv/Bq ≡ C_{HTO} (this is the inhalation dose coefficient!, according to ICRP 71, page 37; in the case of tritium, the inhaled activity is the equal to the intake, because of that one could use the inhalation dose coefficient here).

The Committed Dose Equivalent is:

$$H_{50} = 156{,}600 \text{ Bq} \cdot C_{HTO} = 2.82 \text{ µSv}$$

The dose for the first minute is:

$$H_{\text{first minute}} = x \cdot 2.82 \text{ µSv} = 5.12 \cdot 10^{-5} \cdot 2.82 \text{ µSv} = 1.44 \cdot 10^{-4} \text{ µSv}$$

And so the daily effective dose during equilibrium is:

$$H_d = 1.44 \cdot 10^{-4} \text{ µSv} \cdot 60 \cdot 24 = 0.208 \text{ µSv}$$

or in other words, the dose rate during equilibrium is 0.208 µSv/d

5th step: committed effective dose due to total intake

The total intake has been calculated as product of the number of days, wearing the watch and the average daily intake: 29 days • 13,828 Bq/day = 401,012 Bq

The Committed Dose Equivalent due to total intake is:

$$H_{50} = 1.8 \cdot 10^{-11} \text{ Sv/Bq} \cdot 401{,}012 \text{ Bq} = 7.22 \text{ µSv}$$

F2: Incidental intake of $^{90}Sr/^{90}Y$

F2.1 Case description

Main characteristics

- Member of the public
- Real incidental case
- Ingestion
- Urine measurement

F2.1.1. The event

Description of the working area

Chemical laboratory at a University institute

F2.1.2 *Characteristics of work*

After preparation of her thesis at the University the person was temporarily working from 24.01.1996 until 06.02.1996 with ^{90}Sr in liquid form. During that period no contamination measurements were performed in the laboratory.

F2.1.3 *Reasons for monitoring, initiating event*

During a training course for radiation protection officers of the University a visit to a research reactor in a research centre was performed on 23.03.1996. After this visit a routine contamination check with a hand-foot-monitor revealed significant contamination of the person. Further contamination measurements showed heavy contamination of the person's gloves, coat, blue jeans, bag, and suitcase, the activity concentration being about 10 Bq/cm² and the total activity about 50 - 100 kBq, but no skin contamination was found.

F2.1.4 *Actions taken*

The person's gloves were washed and in the washing water $^{90}Sr/^{90}Y$ was detected by LSC. Incorporation monitoring by urine excretion analysis was initiated immediately. The person was supplied with new clothes and went home. Further investigations in the person's flat showed small amounts of contamination on different surfaces (clothes, bed, and walls). This indicated that the contamination was not due to the visit to the reactor.

F2.1.2 Additional information

F2.1.2.1 *Air monitoring*

None

F2.1.2.2 *Chemical form*

Soluble compound

F2.1.2.3 *Physical characteristics, particle size*

Unknown

F2.1.2.4 *Nose swab, bronchial slime or similar*

None

F2.1.2.5 *Skin contamination*

During exposure not measured, and at the date of the initiating event not found

F2.1.2.6 *Wound site activity*

None

F2.1.2.7 *Any intervention used (blocking, chelating, etc)*

None

F2.1.3 Personal data

F2.1.3.1 *Sex*
Female

F2.1.3.2 *Age*
38 y

F2.1.3.3 *Weight*
70 kg

F2.1.4 Body monitoring data

F2.1.4.1 *Whole body activity measurement*
None

F2.1.4.2 *Organ activity measurement*
None

F2.1.5 Excretion monitoring data

F2.1.5.1 *Urine activity measurement*
One 24-h-urine sample was taken immediately after the discovery of the contamination and then follow-up measurements were performed. The data given in the table below refer to the activity of ^{90}Sr in radiological equilibrium with ^{90}Y. The uncertainty is expressed in terms of one standard deviation.

Date (DD.MM.YY)	^{90}Sr-concentration [mBq/24-h urine]
23.03.96	492 ± 60
23.05.96	157 ± 25
23.06.96	91 ± 20
28.07.96	65 ±17
22.09.96	74 ±20
21.07.97	56 ±15
01.02.98	50 ±14

F2.1.5.2 *Feces activity measurement*
None

F2.1.6 Other comments relevant to intake and dose calculation

One can assume that the intake occurred in the time between 24.01.1996 and 06.02.1996 by ingestion. One also can assume radioactive equilibrium between ^{90}Sr and ^{90}Y at the time of intake.

F2.1.7 Results

Intake of ^{90}Sr [Bq]	Committed effective dose due to ^{90}Sr and ^{90}Y E(50) [mSv]

Additional comments

F2.1.7.1 Computer code(s) applied
F2.1.7.2 Intake assumptions (path of intake)
F2.1.7.3 Model(s) applied
F2.1.7.3.1 Standard ICRP models
F2.1.7.3.1.1 Type of models
F2.1.7.3.1.2 Model parameters (inhalation class or clearance type, AMAD etc.)
F2.1.7.3.2 Other models
F2.1.7.3.2.1 Reason for applying other models
F2.1.7.3.2.2 Type of models
F2.1.7.3.2.3 Characteristical parameters
F.2.1.7.4 Data handling
F.2.1.7.4.1 Data used for calculation (all data or selected data; please comment especially on the handling of the urine excretion value of day 1108 and also on the handling of the ^{241}Am organ activity values.)
F.2.1.7.4.2 Methods for handling of measurements below detection limit
F.2.1.7.5 Additional information

F2.2 Answers of the participants

Table F2.2.1: Results (outliers in shadow)

Participant ID	Intake of ^{90}Sr [Bq]	Committed effective dose due to ^{90}Sr and ^{90}Y [mSv]
1	3560	0.028
2	7800	0.280
3	2700	0.076
4	5200	0.160
5	1820	0.054
6	3120	0.110
7	3000	0.080
9	3100	0.087
11	2600	0.100
12	2753	0.077
13	2500	0.030
14	2090	0.062
15	2000	0.060

Table F2.2.1 (continued): Results (outliers in shadow)

Participant ID	Intake of ^{90}Sr [Bq]	Committed effective dose due to ^{90}Sr and ^{90}Y [mSv]
17	2670	0.079
18	2709	0.600
19	2600	0.091
20	3200	0.110
21	5000	0.200
23	7000	0.250
25	2700	0.100
28	3310	0.093
29	1700	0.052
30	3200	0.110
32	3410	0.370
33	4200	0.260
34	2380	0.110
35	2600	0.080
37	1600	0.004
38	1250	0.088
39	2500	7.600
41	3200	0.090
42	965	0.060
43	4600	0.128
44	25000	0.800
45	2462	0.069
46	1638	0.050
47	2433	0.088
49	2377	0.073
GM	2696	0.093
GSD	1.37	1.78
AM	2829	0.110
ASD	907	0.076
Minimum	965	0.004
Maximum	25000	7.6

Table F2.2.2: Model(s) applied

Participant ID	Respiratory tract	GI-Tract	Systemic biokinetics	Urinary excretion	f1 – factor (^{90}Sr)	Tissue weighting factor	Dose coefficient (Sv Bq^{-1})
1							
2		ICRP 30	ICRP 54	ICRP 54	0.3		
3		ICRP 30	ICRP 54	ICRP 54	0.3		ICRP 68
4		ICRP 30	ICRP 54	ICRP 54	0.3		ICRP 72/78
5		ICRP 30	ICRP 67		0.3	ICRP 60	
6			Johnson		0.3		

Table F2.2.2 (continued): Model(s) applied

Participant ID	Respiratory tract	GI-Tract	Systemic biokinetics	Urinary excretion	f1 – factor (^{90}Sr)	Tissue weighting factor	Dose coefficient (Sv Bq^{-1})
7		ICRP 30	ICRP 20/67	ICRP 54	0.3	ICRP 60	ICRP 68
9		ICRP 30	ICRP 30	ICRP 54	0.3		
11	ICRP 66 (F, 1 μm)				0.3		
12					0.3		
13	ICRP 66 (5 μm)						
14			ICRP 30		0.3		$2.956 .10^{-8}$ (LUDEP calculation)
15				ICRP 54			$2.8 . 10^{-8}$
17				ICRP 54	0.3		
18			ICRP 30		(^{90}Y=10^{-4})		
19		ICRP 30	Johnson				
20			Johnson		0.3		
21				ICRP 54	0.3		
23			ICRP 30				
25		ICRP 30	ICRP 54	ICRP 54	0.3 (^{90}Y=10^{-4})		
28			ICRP 30		0.3 (^{90}Y=10^{-4})		IAEA SS115
29			ICRP 67		0.3	ICRP 60	ICRP 67
30		ICRP 30	Johnson		0.3		
32	ICRP 66						
33			ICRP 30				
34		ICRP 30	ICRP 30	ICRP 54	0.3	ICRP 60	LUDEP
35			ICRP 20		0.3		ICRP 68
37					0.01		ICRP 68 ($2.7.10^{-9}$)
38		ICRP 54	ICRP 56		0.4		ICRP 56 and 72 (15 y)
39							
41			ICRP 30		0.3		$2.7 . 10^{-8}$
42	ICRP 54 (D, 1 μm)			ICRP 54	0.3		
43			ICRP 20 ICRP 54		0.3		ICRP 67
44			ICRP 56 ICRP 67				$3..2. 10^{-8}$
45			ICRP 54		ICRP 68		ICRP 68
46			ICRP 67		0.3 (^{90}Y=10^{-4})		ICRP 68
47			ICRP 30				$2.8 . 10^{-8}$
49			ICRP 54	ICRP 54	0.3		ICRP 68

Table F2.2.3: Data handling

Participant ID	Mode of intake	Time of intake	Data used for calculation
1	continuous		all
2	constant rate continuous ingestion	from 24.01.96 to 06.02.96	last 3 data
3	acute ingestion	06.02.96	
4	acute ingestion	between 24.0196 and 06.02.96	all
5	acute ingestion	31.01.96	urine data
6	continuous ingestion	from 24.01.96 to 06.02.96	all
7	acute and chronic ingestion	various	all
9	acute ingestion	30.01.96	all
11	acute inhalation	31.01.96	all
12	acute ingestion	31.01.96	all
13	acute inhalation	01.02.96	all
14	acute ingestion	06.02.96	all except the last 3 urine data
15	acute ingestion	30.01.96	last 2 urine data
17	acute ingestion	24.01.96	all
18	acute ingestion	31.01.96	all
19	acute ingestion	04.02.96	all
20	acute ingestion	30.01.96	all
21	acute ingestion	30.01.96	predominantly late excretion
23	acute ingestion	31.01.96	
25	acute ingestion	31.01.96	all
28	acute ingestion	30.01.96	all
29	acute ingestion	01.02.96 (obtained by a computer fit to data)	all
30	acute ingestion	31.01.96	all
32	acute inhalation		
33	acute ingestion	30.01.96	all
34	acute ingestion	30.01.96	all
35	acute ingestion	31.01.96	all
37	acute ingestion	31.01.96	
38	acute ingestion	31.01.96	first 4 data
39	acute ingestion	30.01.96	
41	acute ingestion	31.01.96	all
42	acute inhalation	24.01.96	all
43	acute ingestion	31.01.96	all
44	acute ingestion	30.01.96	
45	acute ingestion	31.01.96	all
46	acute ingestion	06.02.96	all
47	acute ingestion	30.01.96	
49	acute ingestion	31.01.96	all

Table F2.2.4: Additional information

Participant ID	
2	The standard models could not give a good fit to all data; thus only the last data have been used, which are more representative for long-term retention.
3	Alternative approach for continious ingestion: Intake 2500 Bq; committed effective dose 0.07 mSv.
4	Two calculations have been performed for acute intake on 24.01.96 and 06.02.96, respectively, and the results were averaged; ; INDOS and LUDEP provided the same results.
5	Alternative assessment for acute intake on 24.01.96 results in 2020 Bq intake; second alternative assessment based on ICRP54 results in 2430 Bq intake.
6	
7	Four different approaches were applied for acute and chronic intake using ICRP20 and ICRP67, respectively; the reported result is a rounded average of these approaches.
14	When using all data the intake is 2210 Bq; the dose coefficient from LUDEP is 2.956 E-08 (used here) as compared to 2.8 E-08 from ICRP78.
15	The last term in the urinary excretion function given in ICRP 54 also represent the excretion in the case of inhalation. This term dominates (<95 %) for times >430 days after intake. Thus we used only the last two data points.
19	Alternative assessment using LUDEP for acute ingestion on 04.02.96 resulted in 2190 Bq intake and 0.1 mSv committed effective dose; another alternative assessment using CINDY for chronic ingestion from 24.01.96 to 06.02.96 resulted in 3120 Bq intake and 0.11 mSv committed effective dose.
20	Alternative assessment for chronic intake from 24.01.96 to 06.02.96 resulted in 3400 Bq intake and 0.11 mSv committed effective dose.
25	Four different input patterns have been considered and fairly similar results were obtained.
28	
29	Amount and date of intake have been obtained by a best fit procedure.
35	A 6 exponential function for the retention function in ICRP 20 has been used.
37	Dose conversion factor 2.7 E-09 Sv/Bq (related to f1=0.01for Sr-Titanate) was used.
38	For Sr-90 dose coefficient 6.7 E-08 Sv/Bq from ICRP56 for age 15 y has been used; for Y-90 dose coefficient 3.3 E-09 Sv/Bq from ICRP72 has been used.
41	Alternative assessment assuming chronic ingestion for the whole exposure period resulted in 3500 Bq intake.
43	The initial excretion rate and the intake were derived by using two successive fitting procedure to the experimental data and using ICRP54 excretion model.
44	The committed effective dose was calculated considering dose coefficient of 3.2E-8 Sv / Bq for females. Yttrium-90 intake was not considered in committed effective dose calculation.
45	
46	Values of 0.046 mSv committed effective dose for Sr-90 and 0.004 mSv for Y-90 were calculated assuming type F for Sr-90 and type M for Y-90 when using dose factors from ICRP68. Alternative date of 24.01.96 for intake was also assumed and a value of 2376 Bq was obtained.
47	Dose coefficient = $2.7 \cdot 10^{-8}$ for the public; used LUDEP and DECODIX code.
49	Dose coefficient for Sr-90 = 2.8 E-8 Sv/Bq, for Y-90 = 2.7 E-9 Sv/Bq. Empirically derived excretion functions have been used.

F2.3 Example I

Assessed by: *C. Hurtgen, SCK•CEN, Belgian Nuclear Research Centre, Mol, Belgium.*

Introduction

This contamination case by ^{90}Sr / ^{90}Y of a member of the public was described as a real incidental contamination for which ingestion is assume to be the pathway. The exact time of intake is unknown but the time lag is restricted to a period of 13 days from 24 January to 6 February 1996. The urine measurements provided span from 59 to 739 days after the begining of the possible intake period.

Excretion function

The ICRP 54 gives for the urinary excretion function :

$$e^{a}_{B,u} = 0.13 \bullet e^{-0.693\frac{t}{3}} + 0.0013 \bullet e^{-0.693\frac{t}{44}} + 2.4\,10^{-5} \bullet e^{-0.693\frac{t}{4000}}$$

Another excretion function is given by Newton et al. (1990)

$$U_t = 0.0326 \bullet e^{-0.164\,t} + 0.0730 \bullet t^{-1.23}$$

These two function are represented graphically in Fig F2.3.1. For this case, the excretion function from ICRP 54 has been used.

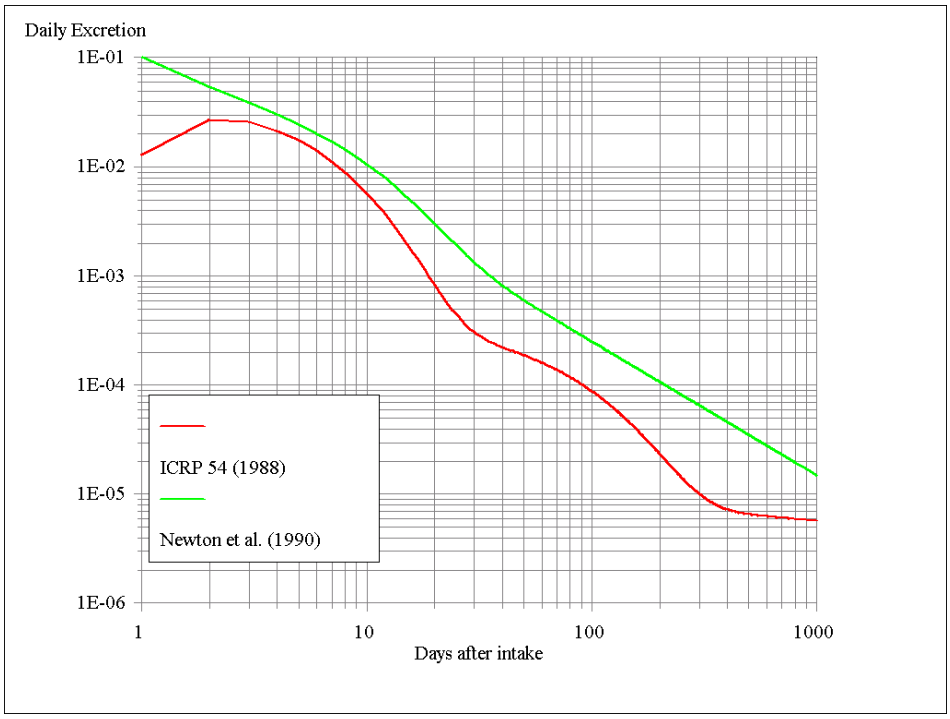


Fig F2.3.1: Excretion curves in function of time

Computer Code

Ludep 2.06 has been used for the estimation of the intake with the following parameters:

- Intake regime: acute ingestion;
- Radionuclide: ^{90}Sr merged with ^{90}Y from ICRP 38 database;
- Biokinetic model: Sr(D)V.MOD which means Sr biokinetic model for class D compounds with the bone Volume dosimetry classification;
- F_1 = 0.3, the fractional absorption in the gastrointestinal tract;

For the estimation of the intake, the ICRP 54 function available in Ludep, has been used. It is possible in Ludep to use other function. The "INTAKE ESTIMATION" option in Ludep enables excretion rates to be scaled to fit the measured data in order to estimate the magnitude of an intake. Different types of uncertainties on the data are available for the intake estimation. Here as the urine data contain errors on the measurements, ERROR INCLUDED IN DATA SET option has been used.

Intake Estimation

Another parameter which needed to be set up is the date of intake. The possible period of intake spanned from 24.01.96 until 06.02.96. The Intake Estimation was performed using these two dates and also using the mid-interval date of 30.01.96.

The results obtained using all the urine data available are:

- 24.01.96 2670 ± 368 Bq 13.8 % relative error
- 30.01.96 2450 ± 347 Bq 14.2 % relative error
- 06.02.96 2210 ± 322 Bq 15.6 % relative error

If the last 3 urine data are excluded from the intake estimation calculation, the following results are obtained:

- 24.01.96 2510 ± 209 Bq 8.3 % of relative error
- 30.01.96 2310 ± 186 Bq 8.1 % of relative error
- **06.02.96 2090 ± 159 Bq** 7.6 % of relative error

Thus dropping the last 3 urine data reduces the intake by around 5 % and I decide to look for the intake estimation in these results on the perhaps fallacious assumption that the relative error was smaller.

The next point is to choose the date of intake. Looking at the fit of the data with the excretion curve Fig F2.3.2, does not help very much as visually no variation could be observed. The date of 06.02.96 was chosen just on the base of the lowest relative error in the estimation of the intake and perhaps influence by the curious fact that the lowest relative error on the intake was obtained if the date was set up to 23.06.96 with a result of

- 23.06.96 1500 ± 33 Bq 2.2 % of relative error

Committed Effective Dose

Ingestion Dose Coefficient for ^{90}Sr / ^{90}Y can be found in ICRP 67 or ICRP 78:

$$e(50) = 2.8\ 10^{-8}\ \text{Sv / Bq}$$

Calculated with Ludep 2.06, the value obtained for the Ingestion Dose Coefficient is:

$$e(50) = 2.96\ 10^{-8}\ \text{Sv / Bq}$$

and this is the value used for the calculation of the committed effective dose. So the committed effective doses due to ^{90}Sr / ^{90}Y for the possible date of intake are:

- 24.01.96 0.074 mSv
- 30.01.96 0.068 mSv
- **06.02.96 0.062 mSv**

And so the last value of **62 µSv** was chosen as the committed effective dose for this ^{90}Sr contamination case.

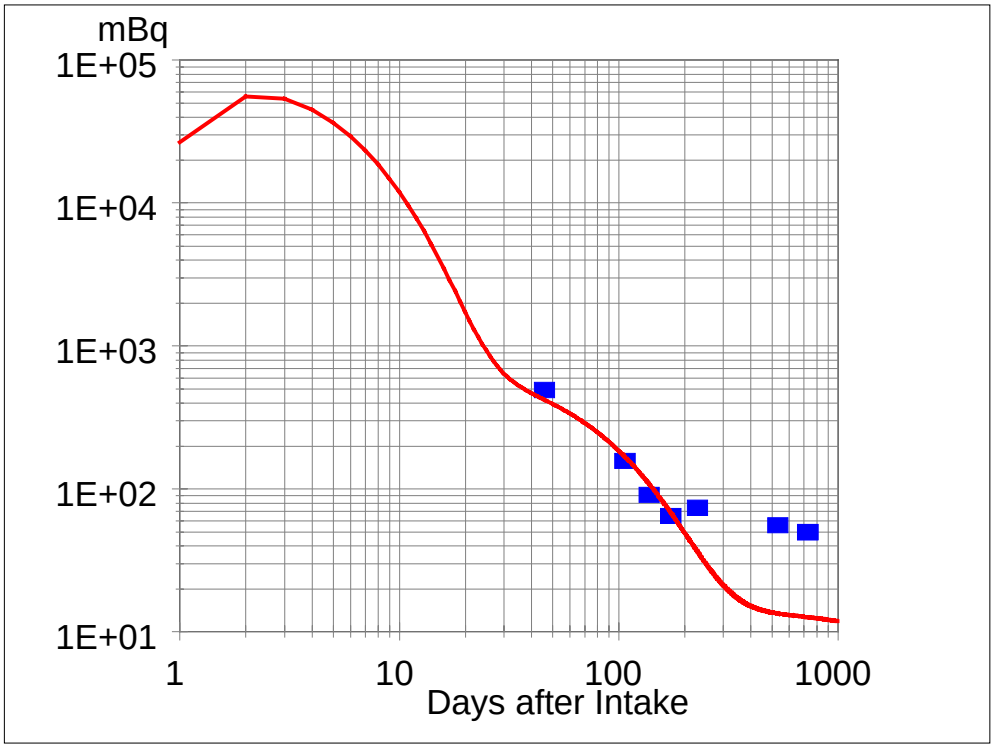


Fig F2.3.2: Urine data fit

F2.4 Example II

Assessed by: *D. Spencer, Harwell Approved Dosimetry Services,*
AEA Technology, UK

Introduction:

^{90}Sr/^{90}Y contamination was found on a person visiting a research reactor during a training course. Her home was also found to be contaminated which showed that the contamination had not resulted from the reactor visit. She had worked with ^{90}Sr previously, while preparing a University thesis. Urine analysis was initiated.

The assessor was required to calculate the intake and dose due to $^{90}Sr/^{90}Y$.

Models and computer tools used for this assessment:

Ludep 2.05 was used to produce a excretion curve based on an intake by ingestion. The excretion data was then match to the excretion curve using a spreadsheet.

The intake could have happened over a period of many days. The calculated intake proved not to be sensitive to the precise intake date so the midpoint of the intake period was selected. The shapes of calculated excretion and urine measurements did not match exactly.

The size intake was calculated based on each urine measurement. An arithmetic mean of the calculated intakes provided the final value for intake. A weighted fit to the measurements based on the uncertainty in the measurements was considered inappropriate as this gave undue weight to the earlier samples, as the uncertainties are smaller as a fraction. The random uncertainties do not reflect the systematic uncertainties in the ICRP model.

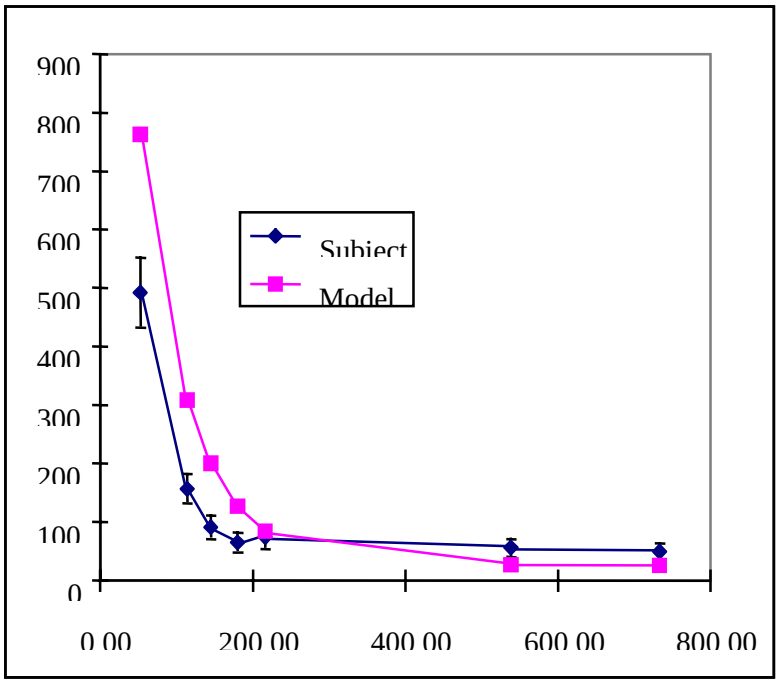


Fig. F2.4.1: Excretion of $^{90}Sr/^{90}Y$ in urine as measured on the subject and calculated with LUDEP 2.05 for ingestion of 4200 Bq on 30/01/1996

The above method assumed that the later urine measurements give just as reasonable estimate of intake as the earlier measurements. Discussion at the intercomparison meeting indicated that this was not the case and the later measurements are likely to be due to intake of environmental $^{90}Sr/^{90}Y$. Therefore it is more appropriate to base the calculated intake on the first four points, which would give a lower calculated intake.

F3 Multiple intake of ^{125}I

F3.1 Case description

Main characteristics

- Radiation worker
- Artificially simulated case
- Inhalation
- Urine and thyroid measurement
- Effect in choosing different routine monitoring periods
- Effect in choosing different monitoring methods (urine or thyroid)
- Effect of intake time assumptions

F3.1.1 The event

F3.1.1.1 *Description of the working area*
Isotope laboratory specially equipped for handling radioiodine in high levels of activity.

F3.1.1.2 *Characteristics of work*
The most characteristic work is labelling different organic compounds by ^{125}I. The chemical preparations are done in ventilated hood. Different phases of the preparational work are connected with different risks of inhalation. This kind of work is repeated several times in a month but not in regular time periods.

F3.1.1.3 *Reasons for monitoring; initiating event*
Monitoring of workers was performed on routine basis and was not connected to any working phase or event. The person of this case started to work in the area on 01.12.95.

F3.1.1.4 *Actions taken*
None

F3.1.2. Additional information

F3.1.2.1 *Air monitoring*
None

F3.1.2.2 *Chemical form*
Mostly iodide and organically bound iodine

F3.1.2.3 *Physical characteristics, particle size*
AMAD = 1 μm

F3.1.2.4 *Nose swab, bronchial slime or similar*
None

F3.1.2.5 *Non removable skin contamination*
None

F3.1.2.6 *Wound site activity*
None

F3.1.2.7 *Any intervention used (blocking, chelating, etc.)*
None

F3.1.3. Personal data

F3.1.3.1 *Sex:* Male

F3.1.3.2 *Age (at the year of the accident):* 40 years
F3.1.3.3 *Weight:* 75 kg

F3.1.4. Body monitoring data

F3.1.4.1 *Whole body activity measurement*
none

F3.1.4.2 *Organ activity measurement*
Thyroid activity has been measured on routine basis. Three sets of data are given in the following table assuming three different monitoring periods (appr. 30, 60 and 90 days).

Date (DD.MM.YY)	^{125}I activity in thyroid [kBq]		
	1*	2*	3*
20.12.95	2.02	2.02	2.02
15.01.96	2.52		
15.02.96	2.19	2.19	
17.03.96	1.25		1.25
18.04.96	0.73	0.73	
20.05.96	0.75		
14.06.96	0.48	0.48	0.48
12.07.96	2.26		
15.09.96	0.67	0.67	0.67
16.10.96	2.51		
21.11.96	2.38	2.38	
13.01.97	0.93	0.93	0.93

* 1, 2 and 3 correspond to approximately 30,60 and 90 days monitoring intervals, respectively.

F3.1.5 Excretion monitoring data

F3.1.5.1 *Urine activity measurement*
Simultaneously with thyroid activity measurements 24 hours urine samples were collected and measured. Three data sets on urinary ^{125}I excretion rates are given in the table below.

Date (DD.MM.YY)	^{125}I activity in 24 hours urine [Bq]		
	1*	2*	3*
20.12.95	7.6	7.6	7.6
15.01.96	12.2		
15.02.96	9.7	9.7	
17.03.96	7.4		7.4
18.04.96	4.4	4.4	
20.05.96	3.7		
14.06.96	2.8	2.8	2.8
12.07.96	9.3		
15.09.96	4.2	4.2	4.2
16.10.96	12.8		
21.11.96	59.5	59.5	
13.01.97	5.6	5.6	5.6

*1, 2 and 3 correspond to approximately 30, 60 and 90 days monitoring intervals, respectively.

F3.1.5.2 *Feces activity measurement*
None

F3.1.6. Other comments relevant for intake and dose estimation

All intakes and corresponding dose values should be estimated from both thyroid (T) and urinary (U) data sets assuming three different routine monitoring intervals (appr. 30, 60 and 90 days). One should not assume less than three days between any intake and the subsequent urine sampling. The calculated results should be given using the attached FORMS OF RESULTS separately for the different monitoring intervals. It is requested to fill in the columns (TABLE A) and the line (TABLE B) to provide the best estimate (Best) based either on thyroid or urine measurements or on some of their combination. The date of intake (TABLE A) should always be the best estimate for both the thyroid and urine values. The dose values in TABLE A and TABLE B should be given only if the dose is derived directly from the thyroid activity.

Beside indicating all assumed intakes and corresponding doses (TABLE A), the summarised results for the intakes occurred during the calendar year of 1996 should also be given (TABLE B). Submitting more results by using different intake and/or dose estimation methods is encouraged and appreciated.

F3.1.7 Results

Table F3.1.7.1: Appr. monitoring interval 30 days

Assumed dates of intakes (DD.MM.YY)	^{125}I intakes [kBq]			Committed equivalent dose of the thyroid H_{th} (50) [mSv]			Committed effective dose E (50) [mSv]		
	T	U	Best	T	U	Best	T	U	Best

Table F3.1.7.2: Appr. monitoring interval 60 days

Assumed dates of intakes (DD.MM.YY)	^{125}I intakes [kBq]			Committed equivalent dose of the thyroid H_{th} (50) [mSv]			Committed effective dose E (50) [mSv]		
	T	U	Best	T	U	Best	T	U	Best

Table F3.1.7.3: Appr. monitoring interval 90 days

Assumed dates of intakes (DD.MM.YY)	^{125}I intakes [kBq]			Committed equivalent dose of the thyroid H_{th} (50) [mSv]			Committed effective dose E (50) [mSv]		
	T	U	Best	T	U	Best	T	U	Best

Table F3.1.7.4: Appr. monitoring interval 30 days

Monitoring method	^{125}I intake in 1996 [kBq]	Committed equivalent dose of the thyroid due to the intake in 1996 (H_{th} (50)) [mSv]	Committed effective dose due to the intake in 1996 (E 50)) [mSv]
Thyroid			
Urine			
Best estimate			

Table F3.1.7.5: Appr. monitoring interval 60 days

Monitoring method	^{125}I intake in 1996 [kBq]	Committed equivalent dose of the thyroid due to the intake in 1996 (H_{th} (50)) [mSv]	Committed effective dose due to the intake in 1996 (E 50)) [mSv]
Thyroid			
Urine			
Best estimate			

Table F3.1.7.6: Appr. monitoring interval 90 days

Monitoring method	^{125}I intake in 1996 [kBq]	Committed equivalent dose of the thyroid due to the intake in 1996 (H_{th} (50)) [mSv]	Committed effective dose due to the intake in 1996 (E 50)) [mSv]
Thyroid			
Urine			
Best estimate			

Additional comments

F3.1.7.1 National guideline(s) applied
F3.1.7.2 Computer code(s) applied
F3.1.7.3 Intake assumptions
- F3.1.7.3.1 Mode of intake (acute, contineous etc.)
- F3.1.7.3.2 Time of intake

F3.1.7.4 Model(s) applied
- F3.1.7.4.1 Standard ICRP models
  - F3.1.7.4.1.1 Type of models
  - F3.1.7.4.1.2 Model parameters (inhalation class or clearance type, AMAD etc.)
- F3.1.7.4.2 Other models
  - F3.1.7.4.2.1 Reason for applying other models
  - F3.1.7.4.2.2 Type of models
  - F3.1.7.4.2.3 Characteristical parameters

F3.1.7.5 Data handling
- F3.1.7.5.1 Data used for calculation (all data or selected data)

F3.1.7.6 Additional information

F3.2 Answers of the participants

Table F3.2.1: Results for 30 days monitoring interval (outliers in shadow)

Participant	Intake in 1996 [kBq]			$H_{th,96}(50)$ [mSv]			$E_{96}(50)$ [mSv]		
ID	T	U	Best	T	U	Best	T	U	Best
1	59.62	50.1	54.2	6.32	5.31	5.75	0.316	0.265	0.29
3	77	226	77	9.84	26.76	9.24	0.41	1.2	0.41
4	111.4	121.7	111.4	11.9	13	11.9	0.6	0.65	0.6
5	89.6	224	89.6	9.39	23.5	9.39	0.471	1.18	0.471
6	77.01	76.63	77.01	8.24	8.2	8.24	0.414	0.412	0.414
9	74	130	102	16	29	12.2	0.5	0.8	0.6
11	32		32	3.2		3.2	0.16		0.16
12	31.38	4.94	31.38	6.9		6.9	0.2		0.2
15	64.83	52.94	57.85	9.62	7.86	8.58	0.48	0.39	0.43
17	87.8	240.1	79.9	9.4	25.68	8.55	0.472	1.291	0.43
18	78.84	95.29	78.84	22.07	26.68	22.07	1.1	1.33	1.1
19	52.5	63.2	49.45	10.52	12.64	9.91	0.316	0.383	0.299
20	54.2	49.8	52	11.9	11	11.4	0.35	0.32	0.34
22	160	13	84						
25	47	45	47	10.4	9.8	10.4	0.31	0.29	0.31
26	47.7		47.7	7.06		7.06	0.356		0.356
27	68	74	54	6.8	7.4	5.5	0.35	0.37	0.28
28	93.731	86.492	90.112	10.029	9.255	9.642	0.497	0.458	0.478
29	84	98	91	9.1	10.6	9.8	0.45	0.53	0.49
30	46.8	51.5	46.8	10.3	11.3	10.3	0.3	0.33	0.3
31	94	159	94	9.4	15.9	9.4	0.479	0.811	0.479
32	15.5	21.8	21.8	3.41	4.8	4.8	0.17	0.24	0.24
33	63.8	69.7	66.8	14	15.3	14.7	0.41	0.45	0.43
34	113	276	113	12	29	12	0.6	1.45	0.6
35	80	82.3	81.1	15	16	15	0.77	0.79	0.78
36	215.6	323.6	215.6	47.3	71.2	47.3	2.2	3.5	2.2
37	111.2	280	111.2	11.1	28	11.1	0.6	14	0.6
38	53	67	60	5.8	7.4	6.6	0.28	0.36	0.32
39	92.3	359.5	92.3	13.5	52.7	13.5	1	4	1
40	164.71	457.43	311.06	27.99	77.75	52.87	0.88	2.45	1.66
41	74	150	112	8	17	12	0.4	0.8	0.6
42	69	93.8	69	15.18	20.64	15.18	0.45	0.61	0.45
43	84.676	76.758	80.717	18.63	16.89	17.76	0.55	0.5	0.52
45	68.309	163.367	116.804	15.028	35.941	25.697	0.444	1.062	0.759
46	74.3	114.4	74.3	7.88	12.08	7.88	0.394	0.604	0.394
47	81	150	115	18	33	12.3	0.5	0.9	0.6
49	56.6	129.7	93.1	12.5	28.5	20.5	0.368	0.843	0.605
50	168	220		3.696	48.4				
GM	76.6	114	73.2	10.0	17.6	10.2	0.428	0.694	0.441
GSD	1.52	2.01	1.43	1.61	2.03	1.54	1.53	2.05	1.53
AM	83.8	144	77.4	11.1	22.6	11.1	0.467	0.924	0.480
ASD	39.1	103	24.6	5.14	17.6	4.88	0.208	0.876	0.207
Minimum	15.5	4.94	21.8	3.2	4.8	3.2	0.16	0.24	0.16
Maximum	215.6	457.43	311.06	47.3	77.75	52.87	2.2	14	2.2

Table F3.2.2: Results for 60 days monitoring interval (outliers in shadow)

Participant	Intake in 1996 [kBq]			Hth,96(50) [mSv]			E96(50) [mSv]		
ID	T	U	Best	T	U	Best	T	U	Best
1	59.21	114.6	71.2	6.28	12.15	7.55	0.314	0.607	0.377
3	73	213	53	8.76	25.56	6.36	0.39	1.13	0.28
4	98.6	78.3	98.6	10.6	8.4	10.6	0.53	0.42	0.53
5	73.3	239	73.3	7.69	25.1	7.69	0.386	1.26	0.386
6	67.65	59.11	67.65	7.239	6.325	7.239	0.3638	0.3178	0.3638
9	65	87	67	14	19	9.8	0.4	0.6	0.5
11	23		23	2.3		2.3	0.12		0.12
12	25.71	9.74	25.71	5.66		5.66	0.17		0.17
15	52.34	34.26	43.3	7.77	5.08	6.43	0.39	0.26	0.32
17	73.2	212.9	67.5	7.82	22.77	7.23	0.395	1.145	0.362
18	46.22	67.92	46.22	12.94	19.02	12.94	0.65	0.95	0.65
19	48.2	42.9	31.75	9.6	8.6	6.35	0.285	0.258	0.191
20	43.8	29.9	36.9	9.6	6.6	8.1	0.28	0.19	0.24
22	87	16	52						
25	39	26	39	8.6	5.8	8.6	0.25	0.17	0.25
26	40.6		40.6	6.01		6.01	0.303		0.303
27	92	83	57	9.2	8.3	5.7	0.46	0.41	0.29
28	64.205	38.046	51.125	6.87	4.071	5.47	0.34	0.202	0.271
29	73	74	74	7.9	8	8	0.39	0.4	0.4
30	27.2	23	27.2	6	5	6	0.18	0.15	0.18
31	66	97	66	6.6	9.7	6.6	0.357	0.495	0.357
32	19	43.6	44.5	4.2	9.6	9.8	0.21	0.48	0.5
33	45.2	43.5	44.3	9.9	9.6	9.8	0.29	0.28	0.29
34	72	226	72	8	24	8	0.4	1.2	0.4
35	44.7	47.3	46	8.5	9	8.7	0.43	0.45	0.44
36	216.6	299.2	216.6	47.4	65.8	47.4	2.4	3.2	2.4
37	61.6	156.7	61.6	6.2	15.7	6.2	0.3	0.8	0.3
38	43	35	39	4.7	3.9	4.3	0.23	0.19	0.21
39	78.8	183.1	78.8	11.5	26.8	11.5	0.87	2	0.87
40	102.14	269.4	185.67	17.37	45.8	31.58	0.54	1.44	0.99
41	73	144	109	8	16	12	0.4	0.7	0.6
42	47.5	65	47.5	10.45	14.08	10.45	0.31	0.42	0.31
43	34.46	31.358	32.909	8.27	7.53	7.9	0.22	0.2	0.21
45	59.217	147.4	103.173	13.028	32.428	22.698	0.385	0.958	0.671
46	79.7	51.7	79.7	8.44	5.48	8.44	0.422	0.274	0.422
47	71	101	86	15	22	9.8	0.5	0.6	0.5
49	47.6	104.6	78.1	10.5	23	18.7	0.309	0.68	0.494
GM	56.4	72.4	54.0	8.49	12.4	7.78	0.341	0.512	0.354
GSD	1.45	2.34	1.49	1.38	2.05	1.30	1.36	2.16	1.59
AM	59.9	99.8	58.1	8.92	16.1	8.04	0.357	0.692	0.401
ASD	20.2	79.1	22.1	2.94	13.2	2.10	0.107	0.627	0.188
Minimum	19	9.74	23	2.3	3.9	2.3	0.12	0.15	0.12
Maximum	216.6	299.2	216.6	47.4	65.8	47.4	2.4	3.2	2.4

Table F3.2.3: Results for 90 days monitoring interval (outliers in shadow)

Participant	Intake in 1996 [kBq]			$H_{th,96}(50)$ [mSv]			$E_{96}(50)$ [mSv]		
ID	T	U	Best	T	U	Best	T	U	Best
1	47.1	53.17	48.6	4.99	5.64	5.15	0.25	0.282	0.26
3	54	52	57	6.48	6.24	6.84	0.29	0.28	0.3
4	80.5	81.2	80.5	8.6	8.7	8.6	0.43	0.44	0.43
5	51		51	5.35		5.35	0.268		0.268
6	48.04	49.58	48.04	5.14	5.305	5.14	0.2583	0.2666	0.2583
9	53	38	46	12	8	7.5	0.3	0.2	0.3
11	19		19	1.9		1.9	0.1		0.1
12	19.59	17.45	19.59	4.31		4.31	0.13		0.13
15	39.18	37	38.09	5.81	5.49	5.65	0.29	0.28	0.28
17	53.9	50.3	46.1	5.76	5.38	4.93	0.29	0.271	0.247
18	18.63	12.1	18.63	5.22	3.39	5.22	0.26	0.17	0.26
19	30.8	38.8	31.35	6.14	7.76	6.27	0.185	0.233	0.188
20	29.7	30.6	30.2	6.5	6.7	6.6	0.19	0.2	0.2
22	33	3.7	18						
25	29	28	29	6.5	6.1	6.5	0.19	0.18	0.19
26	29.4		29.4	4.35		4.35	0.219		0.219
27	35	71	18	3.5	7.1	1.8	0.18	0.36	0.092
28	61.239	51.189	56.214	6.553	5.477	6.015	0.325	0.271	0.298
29	124	136	130	13	15	14	0.67	0.74	0.7
30	24.4	26	24.4	5.4	5.7	5.4	0.16	0.17	0.16
31	63	97	63	6.3	9.7	6.3	0.321	0.495	0.321
32	10.3	11.4	11.4	2.3	2.5	2.5	0.115	0.125	0.125
33	42.9	45.3	44.1	9.4	10	9.7	0.28	0.29	0.29
34	76	90	76	8	9	8	0.4	0.45	0.4
35	39.9	43.4	41.7	7.6	8.2	7.9	0.38	0.42	0.4
36	224.8	230.4	224.8	49.6	50.8	49.6	2.4	2.4	2.4
37	37.3	41.5	37.3	3.7	4.2	3.7	0.2	0.2	0.2
38	37	31	34	4.1	3.4	3.7	0.2	0.16	0.18
39	37	38.6	37	5.4	5.7	5.4	0.41	0.43	0.41
40	61.84	71.13	66.485	10.51	12.09	11.3	0.33	0.38	0.35
41	54	50	52	5.9	5.5	5.7	0.3	0.3	0.3
42	49	54	49	10.78	11.88	10.78	0.32	0.35	0.32
43	12.973	14.4	13.687	2.85	3.17	3.01	0.08	0.09	0.09
45	49.481	54.75	52.171	10.886	12.045	11.478	0.322	0.356	0.339
46	40	20.6	40	4.24	2.18	4.24	0.212	0.109	0.212
47	49	34	41	10	7	7.5	0.5	0.2	0.4
49	31.67	35.7	33.6	7	7.8	7.4	0.205	0.232	0.219
GM	40.5	40.4	37.5	5.91	6.34	5.70	0.258	0.260	0.245
GSD	1.45	1.78	1.68	1.56	1.59	1.60	1.50	1.61	1.58
AM	43.2	47.0	42.5	6.60	6.98	6.29	0.284	0.288	0.270
ASD	15.3	26.6	22.6	2.66	3.04	2.75	0.112	0.136	0.120
Minimum	10.3	3.7	11.4	1.9	2.18	1.8	0.08	0.09	0.09
Maximum	224.8	230.4	224.8	49.6	50.8	49.6	2.4	2.4	2.4

Table F3.2.4: Best estimates assuming different monitoring intervals (outliers in shadow)

Participant	Intake in 1996 [kBq]			$H_{th,96}(50)$ [mSv]			$E_{96}(50)$ [mSv]		
ID	30d	60d	90d	30d	60d	90d	30d	60d	90d
1	54.2	71.2	48.6	5.75	7.55	5.15	0.29	0.377	0.26
3	77	53	57	9.24	6.36	6.84	0.41	0.28	0.3
4	111.4	98.6	80.5	11.9	10.6	8.6	0.6	0.53	0.43
5	89.6	73.3	51	9.39	7.69	5.35	0.471	0.386	0.268
6	77.01	67.65	48.04	8.24	7.239	5.14	0.414	0.3638	0.2583
9	102	67	46	12.2	9.8	7.5	0.6	0.5	0.3
11	32	23	19	3.2	2.3	1.9	0.16	0.12	0.1
12	31.38	25.71	19.59	6.9	5.66	4.31	0.2	0.17	0.13
15	57.85	43.3	38.09	8.58	6.43	5.65	0.43	0.32	0.28
17	79.9	67.5	46.1	8.55	7.23	4.93	0.43	0.362	0.247
18	78.84	46.22	18.63	22.07	12.94	5.22	1.1	0.65	0.26
19	49.45	31.75	31.35	9.91	6.35	6.27	0.299	0.191	0.188
20	52	36.9	30.2	11.4	8.1	6.6	0.34	0.24	0.2
22	84	52	18						
25	47	39	29	10.4	8.6	6.5	0.31	0.25	0.19
26	47.7	40.6	29.4	7.06	6.01	4.35	0.356	0.303	0.219
27	54	57	18	5.5	5.7	1.8	0.28	0.29	0.092
28	90.112	51.125	56.214	9.642	5.47	6.015	0.478	0.271	0.298
29	91	74	130	9.8	8	14	0.49	0.4	0.7
30	46.8	27.2	24.4	10.3	6	5.4	0.3	0.18	0.16
31	94	66	63	9.4	6.6	6.3	0.479	0.357	0.321
32	21.8	44.5	11.4	4.8	9.8	2.5	0.24	0.5	0.125
33	66.8	44.3	44.1	14.7	9.8	9.7	0.43	0.29	0.29
34	113	72	76	12	8	8	0.6	0.4	0.4
35	81.1	46	41.7	15	8.7	7.9	0.78	0.44	0.4
36	215.6	216.6	224.8	47.3	47.4	49.6	2.2	2.4	2.4
37	111.2	61.6	37.3	11.1	6.2	3.7	0.6	0.3	0.2
38	60	39	34	6.6	4.3	3.7	0.32	0.21	0.18
39	92.3	78.8	37	13.5	11.5	5.4	1	0.87	0.41
40	311.06	185.67	66.485	52.87	31.58	11.3	1.66	0.99	0.35
41	112	109	52	12	12	5.7	0.6	0.6	0.3
42	69	47.5	49	15.18	10.45	10.78	0.45	0.31	0.32
43	80.717	32.909	13.687	17.76	7.9	3.01	0.52	0.21	0.09
45	116.804	103.173	52.171	25.697	22.698	11.478	0.759	0.671	0.339
46	74.3	79.7	40	7.88	8.44	4.24	0.394	0.422	0.212
47	115	86	41	12.3	9.8	7.5	0.6	0.5	0.4
49	93.1	78.1	33.6	20.5	18.7	7.4	0.605	0.494	0.219
50									
GM	73.2	54.0	37.5	11.1	7.78	5.70	0.441	0.354	0.245
GSD	1.43	1.49	1.68	1.75	1.30	1.60	1.53	1.59	1.58
AM	77.4	58.1	42.5	11.1	8.04	6.29	0.480	0.401	0.270
ASD	24.6	22.1	22.6	4.88	2.10	2.75	0.207	0.188	0.120
Minimum	21.8	23	11.4	3.2	2.3	1.8	0.16	0.12	0.09
Maximum	311.06	216.6	224.8	52.87	47.4	49.6	2.2	2.4	2.4

Table F3.2.5: Computer codes and data handling

Participant ID	Computer codes applied	Data used for calculation
1	In house, LUDEP1.1	all
3	n.s.	
4	LUDEP 2.05, MS EXCEL	all
5	IMBA (Integrated modules for bioassay methods)	all
6	LUDEP 2.05	all
9	DECODIX plus CINDY	all
11	none	all thyroid data
12	n.s.	all
15	LUDEP 2.05	all
17	LUDEP 2.05	all
18	none	all
19	CINDY	all
20	none	all exept urine of 21.11.96
22	none	all
25	in house	all except urine of 21.11.96
26	n.s.	n.s.
27	in house	all
28	LUDEP	all
29	IDSS 2.0, IMIE 3.0	all
30	none	all (exept urine excretion from 21.11.96)
31	In house (InDose)	all
32	none	all except urine measurement of 21.11.96
33	BAP	all
34	LUDEP 2.0	all
35	in house	all
36	n.s.	selected data according to criteria >DIL/3
37	n.s.	n.s.
38	In house	all
39	LUDEP 2.04, MS EXCEL	all
40	none	all
41	LUDEP	all
42	n.s.	n.s.
43	n.s.	n.s.
45	in house	all
46	in house (ERC)	all
47	in house, DECODIX	all
49	n.s.	n.s.
50	n.s.	n.s.

Table F3.2.6: Intake assumptions

Participant ID	Mode of intake	Time of intake
1	repeated intake by inhalation	
3	acute	1.) mid point, 2.) estimate from thyr. and ur.data
4	acute inhalation	intake at mid points of the monitoring interval
5	series of continuous intakes	see additional comments
6	multiple inhalation	see additional comments
9	multiple inhalation	midpoint between measurements
11	repeated	midpoint between measurements
12	repeated intake	
15	acute	Best match of thyroid and urine data
17	repeated intake	derived from thyroid and urine data simultaneously
18	repeated	midpoint of monitoring interval
19	repeated	n.s.
20	single repeated intake	in the middle of the interval
22	constant intake during each interval	not relevant
25	series of acute intakes	mid-dates between samples
26	n.s.	n.s.
27	acute single intake between two measurements	see below at additional informations
28	repeated intake by inhalation	see Tables A1-A3
29	n.s.	n.s.
30	acute	midpoint in between two measurements
31	series of acute intakes	mid point between of monitoring intervals
32	acute	continuous with 4 acute events
33	multiple acute	Best match of thyroid and urine data
34	acute inhalation	mid point of monitoring intervals
35	acute intake	best to match thyr. and ur. data or most conserv.
36	continious intake	half of the nominal monitoring interval
37	continuous	n.s.
38	series of acute intakes	middle of monitoring interval except one interval
39	inhalation	08.12.95
40	acute intaje	mid point of monitoring interval
41	Acute inhalation	middle of the monitoring period
42	repeated intake	n.s.
43	repeated acute	optimised from thyroid and urine measurements
45	acute inhalation	mid time of monitoring period
46	acute	mid point of the monitoring interval
47	multiple inhalation	midpoint in between the measurements
49	n.s.	n.s.
50	n.s.	n.s.

Table F3.2.7: Models and model parameters applied

Participant ID	Respiratory tract	Systemic biokinetics	Urinary excretion	Tissue weighting factor	Dose coefficient
1	ICRP 30	ICRP 30	ICRP 30		
3	ICRP 66	ICRP 54	ICRP 54		ICRP 68
4	ICRP 66	ICRP 54	ICRP 54		ICRP 68
5	ICRP 66	ICRP 67	ICRP 67	0.05	
6	ICRP 54	ICRP 54	ICRP 54		
9	ICRP 30	ICRP 30	ICRP 30		
11	ICRP 54	ICRP 54	ICRP 54	0.05	
12		$T_{1/2}$=40 d			
15	ICRP 54	ICRP 54	ICRP 54	.	
17	ICRP 66	ICRP 30	ICRP 54		
18	ICRP 30	ICRP 54	ICRP 54		ICRP 68
19	ICRP 54	ICRP 54	ICRP 54		
20	ICRP 54	ICRP 54	ICRP 54		
22	ICRP 66 as in 78	ICRP 67 as in 78	ICRP 67 as in 78		ICRP 53
25	ICRP 30	ICRP 54	ICRP 54	0.03	
26					
27	ICRP 66	ICRP 56	ICRP 56		ICRP 71
28	ICRP 66	ICRP 54	ICRP 30		
29	ICRP 66	ICRP 67	ICRP 67		
30	ICRP 30	ICRP 54	ICRP 54		
31	ICRP 66	ICRP 56	ICRP 56		ICRP 71
32	ICRP 30	ICRP 54	ICRP 54		
33	ICRP 30	ICRP 30	ICRP 30		
34	ICRP 66	ICRP 30	ICRP 54	0.05	ICRP 71
35	ICRP 30	ICRP 54	ICRP 54		
36	ICRP 54	ICRP 54	ICRP 54	0.05	ICRP 61
37	ICRP 66				ICRP 68
38	ICRP 54	ICRP 54	ICRP 54		ICRP 68
39					
40	ICRP 66	ICRP 54	ICRP 54		
41	ICRP 66				ICRP 68
42	ICRP 54	ICRP 54	ICRP 54	0.03	
43	ICRP 54	ICRP 54	ICRP 54		
45	ICRP 54	ICRP 54	ICRP 54		ICRP 54
46	ICRP 66	ICRP 56	ICRP 56	0.05	ICRP 68
47	ICRP 54	ICRP 54	ICRP 54		

Table F3.2.8: Additional information

Participant ID	Additional information
3	In tables B the first two lines refer to the method 1.) in which the time of intake was assumed to be in the middle of the monitoring interval; the third lines contain the best estimate determined from both thyroid and urine measurements simultaneously.
5	Three alternative approaches A, B and C have been made. A is based on LUDEP 2.05 whereas B and C are based on IMBA, assuming a series of single intakes (B) and a series of continuous intakes (C); the reported results are for approach C.
6	The time of intake was defined for any interval to give an optimum consistence of thyroid and urine data
9	In addition to the midpoint approach, the thyroid dose also has been estimated directly by integration of the organ burden, and this latter result was assumed to be the best estimate
11	Only the thyroid data were considered in providing the final results.
12	Alternative assessment has been also performed based on ICRP54 iodine model but not indicated in te Tables of results.
15	For Tables A1 and A2 more results have been provided than can be entered into the database. In Table A1 the T and U based results refer to other intake dates than the best estimates; thus only the best estimates can be reported.
17	Alternative calculation has been performed using simultaneously thyroid and urine data to evaluate date of intake and amount of intake. This calculation has been considered as best estimate.
18	Thyroid measurements are considered as the best method for intake and dose estimation.
19	The best estimate was calculated in an independent fitting procedure based on both urine and thyroid data.
25	Urine sample result of 21.11.96 omitted because it is found to be inconsistent with the following sample result and with the in-vivo thyroid measurements. An alternative intake regime was also examined where periods of constant chronic exposure were assumed.
26	
27	The best estimate of the date of intake is adjusted to max and min intake values derived from thyroid measurement and the urine per intake ratio.
29	The linear combination of the response functions (retention and excretion function) for acute intakes has been used in the automated fitting of the measured data (see figures).
31	Two alternative evaluations have been done based on thyroid data. One refer to the estimation of the upper limit of intake and doses (conservative estimate) , the other refer to more realistic approach of mid point intake.
35	Dose coefficients are taken from report NRPB-R245
38	Best estimates were calculated as averages of thyroid and urine based results
39	Thyroid dose used, urine treated as inaccurate.
43	Two more alternative methods were applied both based on ICRP 54 reccomendations: in both methods the mid-point concept was selected for time of intakes. The only difference relates to where take into account the contributions due to the previous intakes.
46	An alternative approach has also been made, based on trapezoid method applied for thyroid data. From this calculation theb effective doses for the year 95, 96 and 97 as well as the total committed effective dose and the total intake were derived.
47	The best estimate has been derived by integration of the retention functions (trapez-rule)

F3.3 Example I

Assessed by: *V. Berkovski, Radiation Protection Institute, Scientific Center for Radiation Medicine, Ukraine*

Introduction:

The information provided for this case was that this was an artificially simulated case. A radiation worker had received a continuous inhalation of ^{125}I aerosols with AMAD 1 μm. Mostly iodide and organically bound iodine is inhaled. Monitoring of workers was performed on routine basis and was not connected to any working phase or event. The person of this case started to work in the area on 01.12.95. Three sets of data are given in the following table assuming three different monitoring periods (appr. 30, 60 and 90 days).

The assessors were requested to reconstruct a pattern of intake and doses, which associated with each of intakes.

Models and computer tools used for this assessment:

This case was assessed by the use of the current laboratory models, tools and methods. The models and methods used were

- ICRP30 GI Tract model (with $f_1 = 0.99$);
- ICRP67 systemic retention model (3-compartmental Riggs iodine model),
- ICRP66 Respiratory Tract model,
- ICRP60 and IDSS computer code (Berkovski 1998) (ICRP-67/71 dose calculation methods),
- ICRP38 radionuclide data,
- ORNL gamma-SAF data files for dose assessment, and
- Original assessor's methods for numerical deconvolution of biokinetic response functions, implemented in the IMIE computer code (Berkovski 1999)

In the data approximation the linear combination of biokinetic responses is built in the course of a multi-step optimization process. The semi-automated mode of data fitting helps the assessor to achieve the most reliable results. A subset of the observed series of measurements is used on each step.

The required linear combination has the form:

$$F_n(t) = \sum_{i=1}^{n} a_i R(t - \tau_i), \qquad (1)$$

where

$F_n(t)$ function of time t, which approximates the observed time series of the radionuclide content in the body, organs and bioassay probes;

n number of intervals constituting a time segment [0, t]; in the course of the approximation process n denotes the number of iteration steps;

$R(t)$ response of the biokinetic model for a unit delta-impulse (predicted by the model at time t, a radionuclide content in the body, organs or in bioassay probes after a unit acute intake at t=0);

τ_i time shift of the acute intake i (the result of the optimizing search);

a_i scaling factor for the response to the acute intake i;

The search for the linear combination is performed from the first point of the observed series of measurements, with involving subsequent measurements into the approximation process. By the time t, n time intervals

$$\Delta t_i = t_{i+1} - t_i$$

are used in the optimization task. Together they constitute a time segment

$$[0, t]: \sum_{i=0}^{n-1} t_{i+1} - t_i = t\ .$$

One or several points of measurement series $M(t_j)$ fall on each of the considered time intervals Δt_i, so that

$$t_i \le t_j < t_{i+1}.$$

The sums of squares of absolute or relative deviations can be used as a target function in the optimization. Several data sets and measurements with non-equal precision can be treated. For example, in the case of radioiodine intake the measurements of the iodine content in the thyroid gland $M^{Th}(t)$ and in daily urine excretion $M^{U}(t)$ can be available. In adopting the relative distance method, on the interval n of the approximation, the optimisation problem can be formulated as

$$\begin{cases} \min \sum_{k=j_1}^{j_2} \left(\sum_{i=1}^{n} a_i^{Th} R^{Th}(t_k - \tau_i) - M^{Th}(t_k) \right)^2 \dfrac{1}{\left(M^{Th}(t_k)\sigma_k^{Th} \right)^2} \\ t_{n-1} \le t_k < t_n \\ \min \sum_{l=p_1}^{p_2} \left(\sum_{i=1}^{n} a_i^{U} R^{U}(t_l - \tau_i) - M^{U}(t_l) \right)^2 \dfrac{1}{\left(M^{U}(t_l)\sigma_l^{U} \right)^2} \\ t_{n-1} \le t_l < t_n \\ 0 \le \tau_{n-1} < \tau_n \\ \min | a_i^{Th} - a_i^{U} | \end{cases} \qquad (2)$$

where

k index of the measurement of the radioiodine in the thyroid gland $M^{Th}(t_k)$ at time t_k;

l index of the measurement of radioiodine content in the daily urine probe $M^{U}(t_l)$ at time t_l;

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 process;

τ_i shift in time of the i^{th} acute intake; the shift τ_n for the last term of the sum is a required parameter on the current step of the approximation;

$R^{Th}(t)$, $R^{U}(t)$ response functions of the thyroid gland and urine (daily urine excretion) for the unit delta-impulse;

a_i^{Th}, a_i^{U} scaling factors for the thyroid $R^{Th}(t)$ and urine $R^{U}(t)$ response functions, respectively; the factors a_n^{Th} and a_n^{U} are required parameters in optimization;

σ_k^{Th}, σ_l^{U} standard deviations of measurements of thyroid gland and urine, respectively;

j_1, j_2 index of the extreme left and right points of data series $M^{Th}(t_k)$ included into the interval of approximation n;

l_1, l_2 index of the extreme left and right points of data series $M^{U}(t_l)$ included into the nth interval of approximation.

Instead of the equation $\min|a_i^{Th} - a_i^{U}|$ in (1) an expert's judgement (a manual selection of the 'best fit' curve) can be used in the interactive mode of approximation.

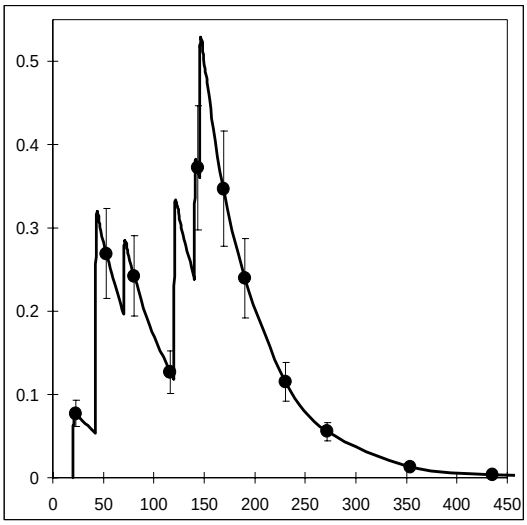
Assessment procedures:

Figure F3.3.1 illustrates the steps in the consecutive data approximation. The artificially generated data set (Figure F3.3.1a) for the case of ^{125}I multiple ingestions has been randomly sampled (points on the graphs). The approximation algorithm works in the following order:

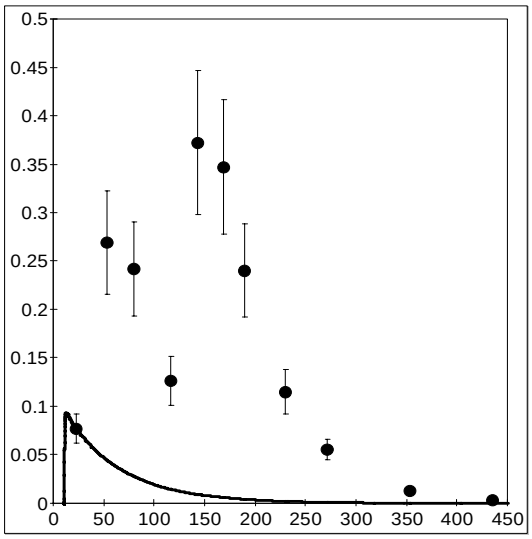
1. Select a first time interval of the approximation, on which a single response can fit the selected subset of the measurement series.
   1.1. Taking into account the subject's anamnesis the assessor inputs the supposed date of the first intake. In the absence of information, and in the automatic mode, the centre of the uncertainty interval can be used.
   1.2. The assessor chooses the last point of the first data subset. One or several data points can fall on the chosen first interval.
2. Perform the data approximation on the selected interval (Figure F3.3.1b).
   2.1. If one data point falls on the selected interval, the computer code calculates the scaling factor a_n without a re-assessment of the date of intake and other conditions of exposure.
   2.2. If two or more data points fall on the selected interval, the re-assessment of the date of intake and exposure conditions is possible. The time shift τ_n of the response function is determined by the 'best fit' search.
   2.3. If the approximation on the Step 2.2 is not satisfactory, the initially selected data subset can be adjusted.
3. Select the next time interval. The left end of a new interval coincides with the right end of the previous interval. The right end of the new interval is chosen as in Step 1.2.
4. Execute Step 2 for the new time interval (Figure F3.3.1c).
5. Execute Steps 3 and 4 for successive data points (Figure F3.3.1d, F3.3.1e, 1f).

Next page:

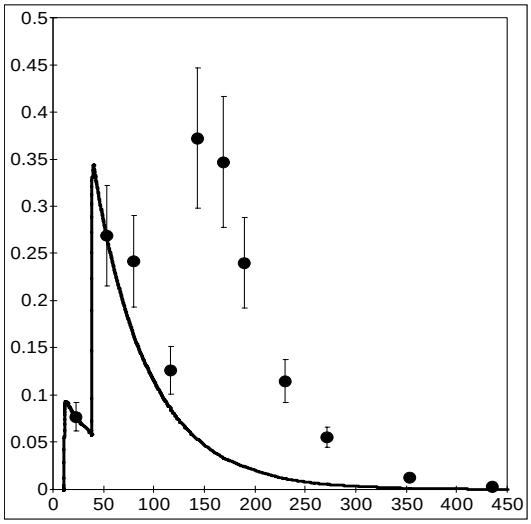
Figure F3.3.1. The illustration of steps in the iterative process of the *in vivo* data fitting. On vertical axes is content (kBq) of ^{125}I in the thyroid of adult man. On horizontal axes is the time (days).



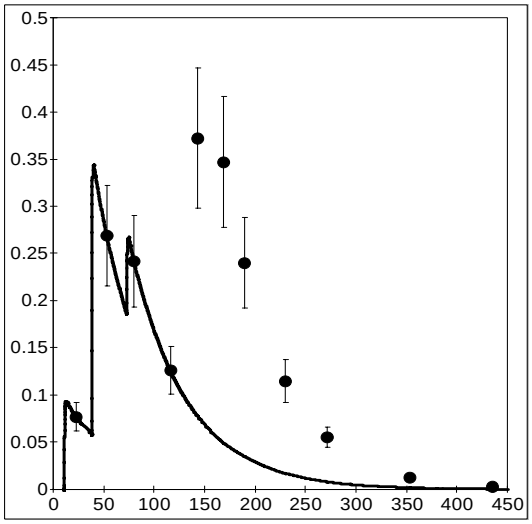
a) Initial data set and 'true' retention curve



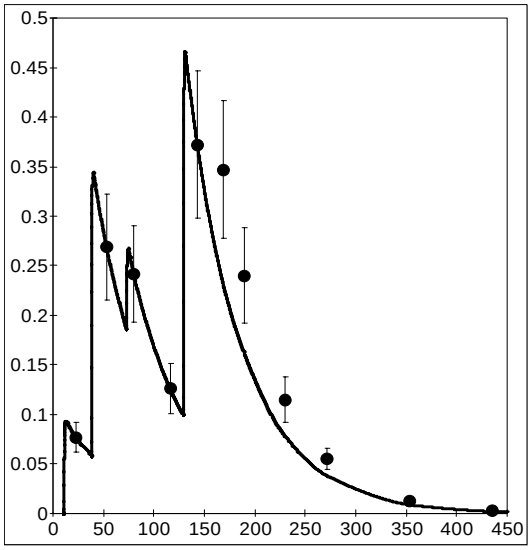
b) First data point is involved



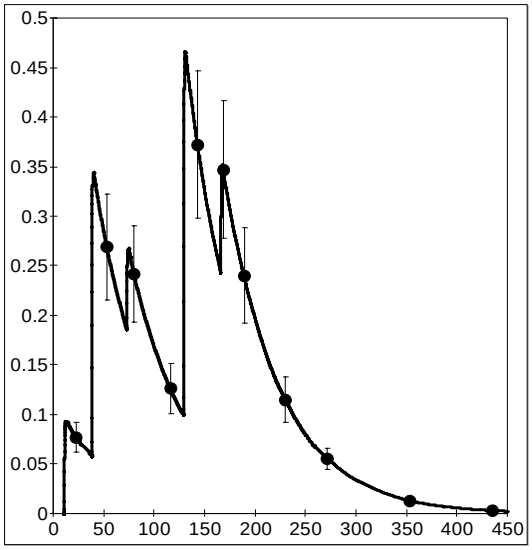
c) Two data points are involved



d) Three data points are involved



e) Five data points are involved



f) final result of reconstr. of intake pattern

Intake and dose assessment:

The IMIE computer code has been used for data set analysis (Table F3.3.1, F3.3.2, F3.3.3). Figures F3.3.2, F3.3.3 and F3.3.4 illustrate the results of intake and dose reconstruction.

Table F3.3.1. Results of intake and dose reconstruction (monitoring interval 30 days)

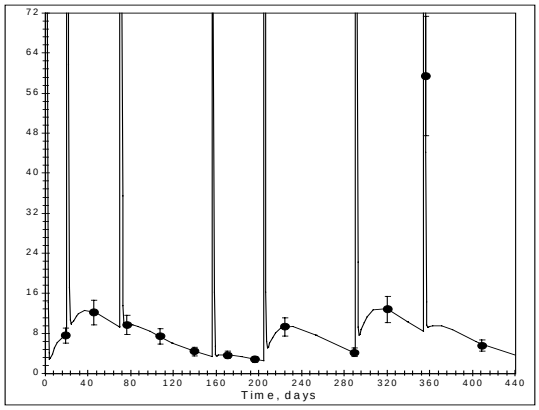
Assumed dates of intakes	^{1215}I intakes [kBq]			Committed equivalent dose of the thyroid H_{th} (50) [mSv]			Committed effective dose E (50) [mSv]		
	T	U	Best	T	U	Best	T	U	Best
01.12.95	27	31	29	2.9	3.3	3.1	0.15	0.17	0.16
21.12.95	19	20	20	2.1	2.2	2.2	0.1	0.11	0.11
09.02.96	8	10	9	0.9	1.1	1.0	0.04	0.05	0.05
05.05.96	4	5	5	0.46	0.53	0.49	0.02	0.03	0.03
22.06.96	26	30	28	2.8	3.2	3.0	0.14	0.16	0.15
16.09.96	35	40	37	3.8	4.3	4.0	0.19	0.21	0.2
19.11.96	11	13	12	1.1	1.4	1.3	0.06	0.07	0.06

Table F3.3.2. Generalized parameters of reconstructed intake (monitoring interval 30 days)

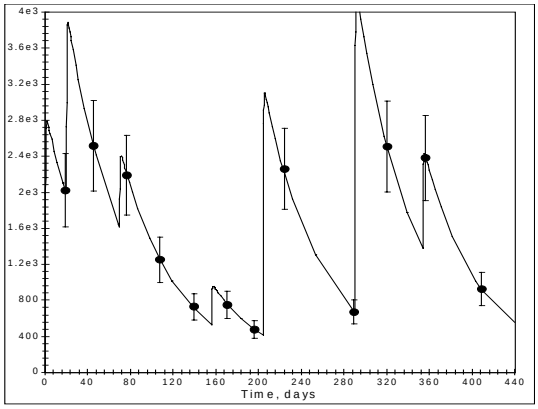
Monitoring method	125I intake in 1996 [kBq]	Committed equivalent dose of the thyroid due to the intake in 1996 (Hth (50)) [mSv]	Committed effective dose due to the intake in 1996 (E 50)) [mSv]
Thyroid	84	9.1	0.45
Urine	98	10.6	0.53
Best estimate	91	9.8	0.49

Table F3.3.3. Comparison of reconstructed intakes, obtained on different monitoring intervals

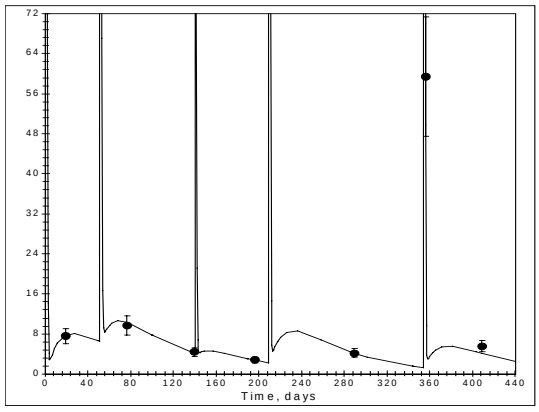
	Total Intake, kBq	Deviation, %
True value	109	-
30 days	140	28%
60 days	103	-6%
90 days	160	47%



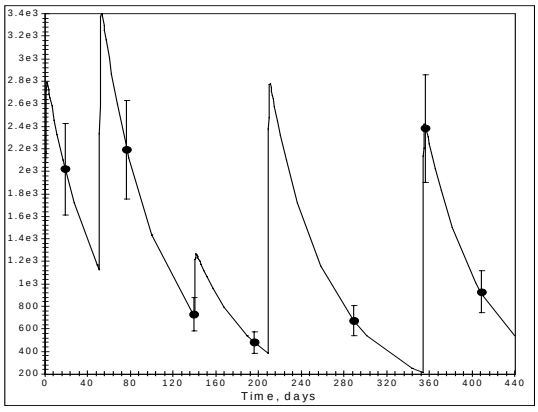
Urine excretion.
30 days monitoring interval



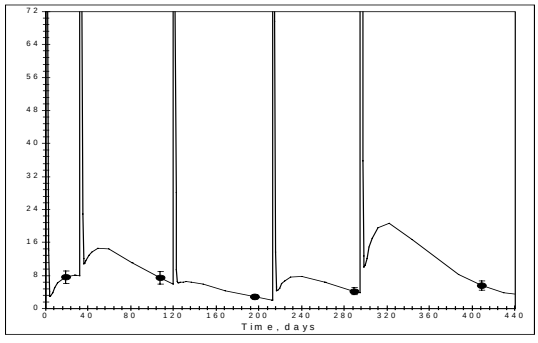
Ativity in thyroid.
30 days monitoring interval



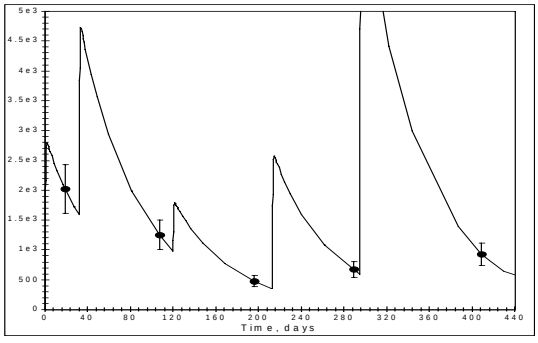
Urine excretion.
60 days monitoring interval



Ativity in thyroid.
60 days monitoring interval



Urine excretion.
90 days monitoring interval



Ativity in thyroid.
90 days monitoring interval

Figure F.3.3.2. Results of intake reconstruction

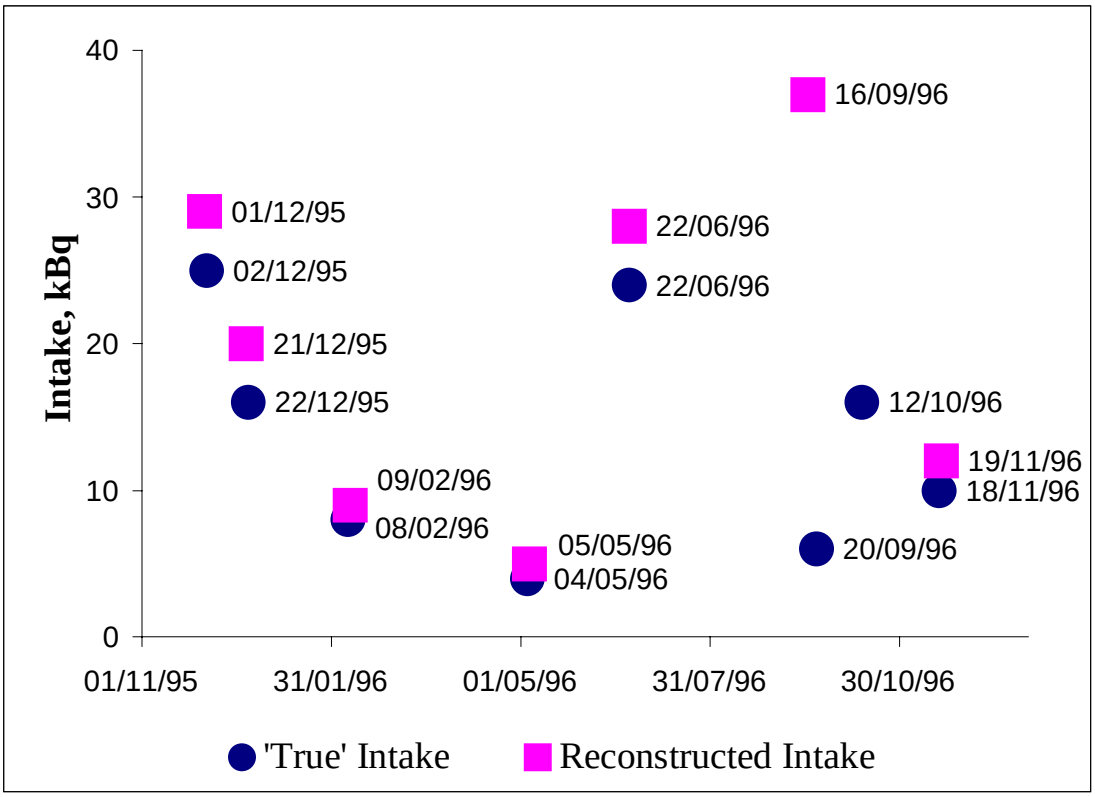


Figure F3.3.3. Comparison of "true" and "reconstructed" intake for 30 days monitoring interval

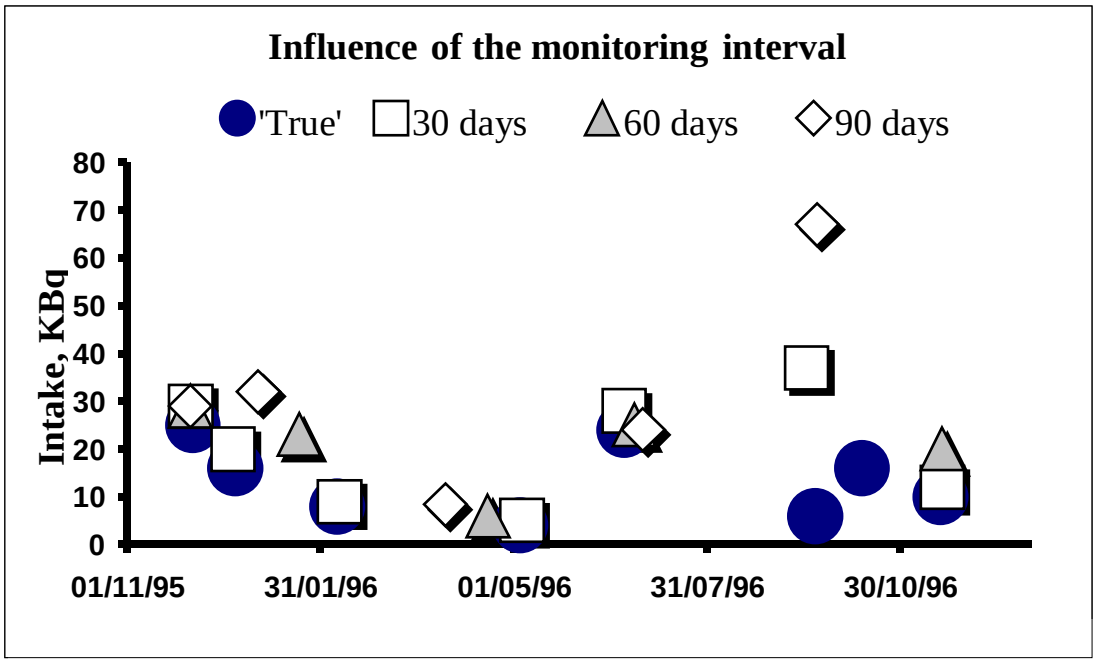


Figure F3.3.4: Influence of the monitoring interval on the reliability of intake reconstruction

F3.4 Example II

Assessed by: *A. Kerekes, National Research Institutes for Radiobiology and Radiohygiene, Budapest*

Basic assumptions

The basic assumptions for parameters and circumstances influencing the intake and internal dose estimation were the followings:

- the incorporation was considered as a series of acute inhalations,
- the intakes occurred at the middles of monitoring intervals except the last but one interval where the intake was 4 d before the measurement on 21.11.96 (cf. 2.3.),
- standard ICRP models and parameters were used (Publ. 54 and 68),
- as the chemical form was mainly iodide the absorption rate was considered as F (solubility class D in the ICRP Publ. 30 methodology),
- the particle size was represented by 1 μm AMAD,
- the "best" estimations were calculated as the averages of intakes and doses derived from the actual thyroid and urine measurements,
- for the correction of the effect of the intake in the previous monitoring intervals an "equivalent" biological half time of 40 d for thyroid was applied, while for the excretion by urine the correction factors were derived from the graphs of ICRP Publ. 54,
- the effective dose factor for inhalation was taken from the ICRP Publ. 68 as $5.3 \cdot 10^{-9}$ Sv/Bq. The thyroid dose was calculated back from the effective value using the tissue weighting factor of 0.05 for thyroid.

Methods

Routine monitoring approach based on the retention and excretion fractions given in ICRP Publ. 54 and 78

The use of the predicted values or fractions of intakes for routine monitoring would give the simplest solution. However, because of its simplicity this method does not take into consideration the effect of previous intakes at all. Consequently, the use of this simple approach might lead to a systematic overestimation to the extent depending on monitoring interval, the intake pattern and the effective half time of the radionuclide (one can assume that it works better for example for ^{131}I than ^{125}I generally).

The degree of overestimation in our case is illustrated in Table F3.4.1 for the intakes calculated from thyroid and urine measurements and comparing to the "true" value of intake given in Section 4.3.3.

As it can be seen from Table F3.4.1 the overestimation is significant for the shortest monitoring interval and is higher for the intakes calculated from the urine measurements. The use of

the new ICRP models led to even worse results in this case, especially for the urine data. It should be noted, that ICRP Publ. 78 suggests to prefer the thyroid measurements unless the time of intake is known as the urinary excretion rate decreases more rapidly than the thyroid activity.

Table F3.4.1: The estimated intakes in 1996 (kBq) based on the application of the routine intake procedure and comparing to the "true" value

	ICRP Publ. 54			ICRP Publ. 78		
Monitoring interval, d	30	60	90	30	60	90
Intake in 1996 from thyroid results	105	54	30	143	80	39
Intake in 1996 from urine results	270	147	30	420	230	46
Best estimation of the intake in 1996	188	101	30	280	155	43
"True" value	68					

Correction of the monitoring results with the effects of the previous intakes

As it was described in the previous section the simple use of the predicted values or fractions of intake for routine monitoring given in the ICRP Publ. 54 and 78 might lead to a significant overestimation of the intake depending on the intake pattern and monitoring interval.

To take into consideration the effects of the previous intakes the following recursive equations were used based on the assumed monitoring time and intake pattern in Fig. F3.4.1:

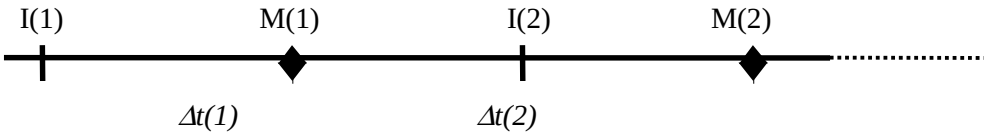


Fig. F3.4.1: The monitoring time and assumed intake pattern

For the thyroid measurements:

$M_T(1) = I(1)*f_T(\Delta t(1))$
$M_T(2) = M_T(1)*exp(-\lambda.\Delta t(2)) + I(2)*f_T(\Delta t(2)/2)$
$M_T(3) = M_T(2)*exp(-\lambda.\Delta t(2)) + I(3)*f_T(\Delta t(2)/2)$
. . .

where $M_T(1)$, ... the results of the first, ... thyroid measurements,
$I(1)$, ... the first, ... intakes
$f_T \approx 0.18*exp(-\lambda.\Delta t(2)/2)$ and $\lambda = 1.7*10^{-2}$ d^{-1}
$\Delta t(1)$ the first, $\Delta t(2)$ the following monitoring intervals
($\Delta t(1)$ was assumed as $\Delta t(2)/2$)

For the urine measurements:

$M_U(1) = I(1)*f_U(\Delta t(1))$
$M_U(2) = I(1)*f_U(\Delta t(1)+\Delta t(2)) + I(2)*f_U(\Delta t(2)/2)$
$M_U(3) = I(1)*f_U(\Delta t(1)+2\Delta t(2)) + I(2)*f_U(3\Delta t(2)/2) + I(3)*f_U(\Delta t(2)/2)$

. . . (up to 6 previous intakes were taken into consideration)

where $M_U(1)$, ... the results of the first, ... urine measurements,
$I(1)$, ... the first, ... intakes
$f_U(t)$ the fraction of intakes excreted by daily urine from the ICRP Publ. 54

The total intakes in 1996 were calculated as the sum of the single intakes occurred that year in all cases. To solve the equations above simple BASIC routines were written to calculate the intake in 1996 and the effective and thyroid doses as well.

The handling of the intake in the monitoring period 16.10 - 21.11 1996

The simultaneous measurements for thyroid and urine gave the opportunity to check the validity of our main basic assumption, i.e. the intakes occurred at the middles of the monitoring intervals, based on the fact, that the retention function for thyroid and the excretion by daily urine show different time dependency.

The intake values derived from thyroid and urine measurements with the mid-point assumption showed acceptable agreement except of the last but one monitoring interval. Here the mid-point assumption gave the intake value as 9.4 kBq from thyroid and 21.5 kBq from urine measurement, clearly indicating a shift of the last intake toward the measurement date of 21.11.96 . Therefore we assumed, that the intake in this interval was only 4 d prior to the sampling, i.e. on 17.11.96 . This assumption led to a reasonable agreement between the estimates of intake from thyroid and urine measurements (7.8 and 8.2 kBq, respectively). The relative differences from the average (best) estimation for the intakes derived from thyroid and urine data were below 30 per cent usually for all the other monitoring intervals.

Results

The summary of results using the method described in the previous sections is given in Tables F3.4.2 - F3.4.4 .

Table F3.4.2: The estimated intakes in 1996 (kBq) derived from the thyroid and urine measurements comparing to the "true" value and the geometric means of the results of participants

	Monitoring intervals, d		
	30 d	60 d	90 d
Thyroid	53	43	37
Urine	67	35	31
Best	60	39	34
Geom. mean (Best)	73	54	38

"true intake": 68 kBq

The results in Table F3.4.2 indicate an increasing underestimation of the intake for the longer monitoring intervals, as we kept the mid-point assumption for all monitoring intervals (except of one). The underestimation for the monitoring interval of 90 days is a factor of 2 . This is in agreement with the results of other participants.

Table F3.4.3: Committed effective dose (mSv) due to the intake in 1996

	Monitoring intervals, d		
	30 d	60 d	90 d
Thyroid	0.28	0.23	0.2
Urine	0.36	0.19	0.16
Best	0.32	0.21	0.18
Geom. mean (Best)	0.46	0.37	0.25

Table F3.4.4: Committed equivalent dose to thyroid (mSv) due to the intake in 1996

	Monitoring intervals, d		
	30 d	60 d	90 d
Thyroid	5.8	4.7	4.1
Urine	7.4	3.9	3.4
Best	6.6	4.3	3.7
Geom. mean (Best)	10.6	7.8	5.7

Conclusions

The use of the relatively simple method described above to correct the effects of previous intakes eliminated the great overestimation resulting in the application of routine monitoring procedure given in ICRP Publ. 54 and 78. However, the mechanical use of the mid-point intake assumption can also lead to a significant discrepancy between the thyroid and urine results and to an under- or overestimation of intake and doses. These errors can be reduced by the adjustment of presumed dates of intakes using the results of the parallel thyroid and urine monitoring.

F4 Continuous intake of ^{137}Cs

F4.1 Case description

Main characteristics

- Member of the public
- Real case connected to Chernobyl accident
- Ingestion
- Whole body measurement
- Dose assessment via intake or directly from the whole body activity

F4.1.1. The event

F4.1.1.1 *Description of the working area*
Not applicable.

F4.1.1.2 *Characteristics of work*
Not occupational exposure.

F4.1.1.3 *Reasons for monitoring; initiating event*
26 April 1986 : Chernobyl accident with spread of fission products and other radionuclides all over Europe. Increase of caesium radionuclides intake due to the environmental contamination.

F4.1.1.4 *Actions taken*
None.

F4.1.2. Additional information

F4.1.2.1 *Air monitoring*
None

F4.1.2.2 *Chemical form*
Unknown.

F4.1.2.3 *Physical characteristics, particle size*
None

F4.1.2.4 *Nose swab, bronchial slime or similar*
Not applicable

F4.1.2.5 *Non removable skin contamination*
None

F4.1.2.6 *Wound site activity*
Not applicable.

F4.1.2.7 *Any intervention used (blocking, chelating, etc.)*
None.

F4.1.3. Personal Data

F4.1.3.1 *Sex*
Male (resident of western Europe)

F4.1.3.2 *Age (at the year of the incident)*
39 y at the beginning of the monitoring period.

F4.1.3.3 *Weight*
About 80 kg.

F4.1.4. Body monitoring data

F4.1.4.1 *Whole body activity measurements*
The results of whole body activity measurements are given in the table below.

Date of measurement DD.MM.YY	^{137}Cs (Bq)
04.06.86	300
23.06.86	671
10.07.86	737
03.09.86	1661
29.09.86	1846
13.10.86	1882
10.11.86	2247
16.12.86	2493
14.01.87	2926
17.02.87	3224
17.03.87	3608
05.05.87	3883
08.06.87	3773
02.07.87	3723
02.09.87	3195
28.09.87	2740
03.11.87	2469
09.12.87	2375
11.01.88	1954
08.03.88	1614
09.05.88	1221
04.07.88	1174
22.09.88	739

F4.1.4.2 *Organ activity measurement*
None

F4.1.5. Excretion monitoring data

F4.1.5.1 *Urine activity measurement*
None

F4.1.5.2 *Feces activity measurement*
None

F4.1.6. Other comments relevant for intake and dose estimation
It is assumed that there was no internal contamination before 26 April 1986.

F4.1.7 Results

	Result	Mode of calculation of effective dose E
Intake from the accident event until the end of the monitoring period (kBq)		
Effective dose (E) received in 1986 (mSv)		□ via intake □ directly from body burden
Effective dose (E) received in 1987 (mSv)		□ via intake □ directly from body burden
Committed effective dose (E(50) due to the intake from the accident until the end of the monitoring period (mSv)		

Additional comments

F4.1.7.1 Computer code(s) applied
F4.1.7.2 Model(s) applied
- F4.1.7.2.1 Standard ICRP models
  - F4.1.7.2.1.1 Type of models
  - F4.1.7.2.1.2 Model parameters (inhalation class or clearance type, AMAD etc.)
- F4.1.7.2.2 Other models
  - F4.1.7.2.2.1 Reason for applying other models
  - F4.1.7.2.2.2 Type of models
  - F4.1.7.2.2.3 Characteristic parameters

F.4.1.7.3 Data used for calculation (all data or selected data)
F.4.1.7.4 Additional information

F4.2 Answers of the participants

Table F4.2.1: Results (outliers in shadow)

Participant ID	Intake [kBq]	Effective dose received in 1986 (mSv)	Via intake (I) Directly (D)	Effective dose received in 1987 (mSv)	Via intake (I) Directly (D)	Committed effective dose (mSv)
1	15.9	0.041	I	0.124	I	0.206
2	14.2	0.04	I	0.073	I	0.2
3	14	0.034	D	0.113	D	0.182

Table F4.2.1(continued): Results (outliers in shadow)

Participant ID	Intake [kBq]	Effective dose received in 1986 (mSv)	Via intake (I) Directly (D)	Effective dose received in 1987 (mSv)	Via intake (I) Directly (D)	Committed effective dose (mSv)
4	8	0.035	I	0.101	I	0.232
5	14.1	0.034	I	0.11	I	0.19
6	8.05	0.04	I	0.11	I	0.2
7	13.01	0.03	I	0.12	I	0.19
9	13.8	0.037	D	0.107	D	0.18
10	14	0.063	D	0.106	D	0.18
11	13.1	0.03	D	0.1	D	0.16
12	18.98	0.0384	I	0.14	I	0.266
13	13.6	0.029	D	0.095	D	0.16
14	9	0.024	I	0.065	I	0.121
15	14	0.033	I	0.094	I	0.182
17	14	0.025	D	0.083	D	0.188
18	20.12	0.063	I	0.155	I	0.261
19	13.8	0.033	I	0.111	I	0.188
20	16.7	0.03	I	0.09	I	0.23
21	14	0.03	D	0.11	D	0.19
23	14.1	0.04	I	0.09	I	0.19
24	12.2					0.11
25	14	0.035	I	0.12	I	0.19
26		0.033	D	0.113	D	
28	23.286	0.021	I	0.151	I	0.303
29	12.5	0.034	D	0.11	D	0.16
30	17.2	0.03	I	0.12	I	0.23
31	14.1					0.1974
32	5.99	0.0365	D	0.0715	D	1.075
33	14.3	0.033	I	0.11	I	0.19
34	13.6	0.078	I	0.095	I	0.182
35	18.7	0.034	I	0.147	I	0.24
38	18.8	0.043	D	0.122	D	0.25
39	4.3	0.05	D	0.12	D	0.028
40	53.37					0.75
41	15	0.034	D	0.111	D	0.21
42	29.823	0.038	I	0.168	I	0.26
43		0.029	D	0.122	D	
44	13	0.031	D	0.11	D	0.17
45	13.952	0.065	I	0.098	I	0.181
46	8.1	0.045	I	0.106	I	0.184
47	14.3	0.033	D	0.11	D	0.18
48	14	0.077	I	0.105	I	0.195
49		0.038	D	0.128	D	0.216
GM	13.907					0.198
GSD	1.26					1.15
AM	14.264					0.200
ASD	3.178					0.029
Minimum	4.3					0.028
Maximum	53.37					1.075

Table F4.2.2: Model(s) applied

Participant ID	Respiratory tract	GI-Tract	Systemic biokinetics	Tissue weighting factor	Dose coefficient (Sv Bq^{-1})
1					
2		ICRP 30	ICRP 54	ICRP 26	ICRP 30
3		ICRP 30	ICRP 54		ICRP 68
4		ICRP 30	ICRP 54		
5		ICRP 30	ICRP 67	ICRP 60	
6			Modified ICRP 30		
7		ICRP 30	ICRP 30/54	ICRP 60	
9	ICRP 30	ICRP 30	ICRP 30		
10			ICRP 54		
11					
12			ICRP 54		ICRP 67
13		ICRP 30	ICRP 30		
14		ICRP 30	ICRP 54	ICRP 60	ICRP 67
15		ICRP 30	ICRP 30		
17		ICRP 30	ICRP 54		
18		ICRP 30	ICRP 30		ICRP 68
19		ICRP 30	ICRP 30		
20		ICRP 30	ICRP 30		
21		ICRP 30	ICRP 30		
23					
24		ICRP 30	ICRP 30		
25		ICRP 30	ICRP 30/54	ICRP 26	
26					
28		ICRP 30	NUREG CR4884		IAEA SS115
29			ICRP 67	ICRP 60	ICRP 67
30		ICRP 30	ICRP 30		
31		ICRP 30	ICRP 67		ICRP 67
32	ICRP 71		ICRP 30		
33		ICRP 30			
34	ICRP 66	ICRP 30	ICRP 54	ICRP 60	ICRP 67
35		ICRP 30	ICRP 54		
38		ICRP 56	ICRP 56		
39		ICRP 30	ICRP 67	ICRP 60	
40		ICRP 54	ICRP 67		
41		ICRP 30	ICRP 30		
42		ICRP 54	ICRP 54		ICRP 30
43		ICRP 30	ICRP 30		
44		ICRP 56	ICRP 67 ICRP 69		
45		ICRP 54	ICRP 54		ICRP 68
46		ICRP 30	ICRP 30		
47		ICRP 30	ICRP 54		
48		ICRP 30	ICRP 30		
49		ICRP 30	ICRP 30		

Table F4.2.3: Data handling

Participant ID	Data used for calculation	f1	Long term Tb (d)
1			
2	all	1	
3	all	1	110
4	all	1	200
5	all	1	
6	all	1	200
7	all	1	110
9	all	1	
10	all		
11	all	1	
12	all		
13	all		
14	untill the end of june 1987		
15	all	0.9	110
17	all	1	
18	all		
19	all		
20	all		
21		1	100
23			
24	Whole body activity data		
25	all	1	110
26			
28	all	1	
29	all	1	110
30	all	1	
31	all	1	
32			
33	all		
34	all		
35	all	1	110
38	all	1	110
39	all	1	110
40	all		
41	all		
42	all	1	110
43			
44			
45	all	1	
46	all		200
47			
48	all	1	
49	all		

Table F4.2.4: Additional information

Participant ID	
1	
2	Two phases of constant rate chronic ingestion assumed:1) May 1986 to August 1987 at 28 Bq/day intake, 2) August 1987 to September 1988 at 4 Bq/day intake.
3	
4	An alternative calculation has also been made assuming another date for the start of the chronic intake which resulted only slightly lower values for the dose. For calculation the empirically defined retention function were used. 20.9 Bq/d constant for 383 d.
5	A good fit to the total body activity data was obtained by assuming the intake to consist of 5 different continuous constant chronic intakes.Constant intake: 13.9, 24.8, 37.4, 14.6 and 4.2 Bq/d.
6	The intake was considered continuous ingestion from 20.05.86 up to 05.05.87. An alternative evaluation has been made for effective dose received in 1986 and 1987 from body burden data using LUDEP code for SEE(WB<-WB) calculation.
7	Intakes were calculated for every measurement assuming intake occurred at the mid point of each measurement interval.
9	The committed effective dose E(50) was derived directly from body burden data by integration of the number of decays over time; the extrapolation for the time after monitoring is not specified. Use of DECODIX software.
10	Deconvolution approach.
11	Effective dose calculated using whole body data; correction for weight.
12	An alternative evaluation has been made for effective dose received in 1986 and 1987 directly from body burden data which resulted almost a factor of 3 less than those evaluated via intake.
13	For effective dose calculation 80 kg body weight was assumed. The additional dose after the end of the measuring period is calculated using the long term part of the retention function and so also committed effective dose was also derived from body burden.
14	3 different intake periods have been defined in which constant daily intake for each period has been evaluated (128 d in 1986 at 11.6 Bq/d, 121 d in 1986 at 21.1. Bq/d, 180 d in 1987 at 27.8 Bq/d). The intake period is assumed to be finished at the end of june 1987.
15	Intake as a function of time: $I(t) = \left(\frac{dc}{dt} + \lambda \cdot c \right) / 0.9 \quad I = \int I(t)dt \quad E = I \cdot e_{50}$
17	It has been assumed that the intake lasts for the period investigated by measurements. Intakes from the earliest periods are subtracted.
18	
19	Several different chronic ingestion have been used.
20	An alternative evaluation has been made for effective dose received in 1986 and 1987 directly from body burden data which resulted almost the same as those evaluated via intake.
21	
23	
24	
25	Constant chronic exposure assumed between measurents.
26	
28	An alternative evaluation has been made for effective dose received in 1986 and 1987 directly from body burden data which resulted in almost the same for the case of 1986 and almost a factor of 3 less in the case of 1987 in comparison with dose calculated via intake.

Table F4.2.4 (continued): Additional information

Participant ID	
29	For a committed effetive dose assessment the measured data were extrapolated after 22.09.88 by ICRP67 retention function (Tb=110 d). The direct evaluation has been applied during the period of measurements.
30	
31	
32	The committed effective dose was calculated from the reported intake activity plus its indicated error $(5.99+3.4).10^3$ Bq. An alternative evaluation has been made for effective dose received in 1986 and 1987 considering ICRP 26 instead of ICRP60 which resulted slightly higher values.
33	For intake calculation a large number of acute intakes has been assumed(1 intake every 5 days).
34	Intakes for each period were calculated assuming a series of acute ingestion at the mid point of the consecutive monitoring dates. Activities from the earliest periods are subtracted.
35	Dose coefficients are taken from report NRPB-R245. It has been assumed a continuous constant intake rate in each monitoring period.
38	Single intakes at mid time between the monitoring intervals were considered.
39	Chronic intake from 26 April 86 to 2 July 87 at constant rate.
40	
41	An alternative evaluation has been made for effective dose received in 1986 and 1987 via intake which resulted in 0.039 mSv for 1986 and 0.112 mSv for 1987.
42	Several different chronic ingestions.
43	
44	It has been assumed that the ingestion occurred at the middle of the measurement interval.
45	Acute ingestion has been assumed at half time between two measurements.
46	In calculation it was assumed that the intake stopped 425 days after the accident. An alternative method to assess effective dose rates was also calculated assuming chronic exposure during the monitoring periods.
47	Use of DECODIX software (Deconvolution approach).
48	First day of intake is 01.05.86; the values given for 1986 and 1987 are committed effective doses due to the intake in the respective year.
49	The effective doses were calculated by means of trapez-rule deviding the monitorinig period into 3 intervals; the committed dose after the monitoring period was calculated from the intake on 22.09.88. 80 kg body weigth assumed.

F4.3 Example I

Assessed by: I. Gómez Parada - Nuclear Regulatory Authority, Buenos Aires, Argentina

Introduction:

This is a real case of continuous ingestion of ^{137}Cs due to the environmental contamination arising from the Chernobyl accident. The subject was a member of the public and the results of whole body counter measurements were provided. The monitoring period spans from the first month after the accident to approximately 880 days later.

The participants were asked to estimate the total intake from the accident until the end of the monitoring period, the effective dose received by the subject in 1986 and 1987 respectively and the committed effective dose due to the total intake.

Models and computer tools used for this assessment:

This case was solved using:

- ICRP 30 model for the gastrointestinal tract.
- ICRP 30 systemic retention model, with a modified biological half-life of the long-term retention.
- CINDY code v. 1.4
- LUDEP code v. 2.06

Intake Assessment

As pattern of intake a constant chronic ingestion for a unique period of time was chosen. It was assumed that the end point of the period of intake was May 5 1987, when according to the measurements, the whole body activity began to decrease. This pattern of intake is an oversimplification of the real situation, as in fact, the rate of intake is not suposed to be constant, but it is expected to increase for certain time and then decrease, due to the build-up and clearance of the radionuclide in the food chain. With these assumptions, a first intake assessment attempt was made, and the effective doses due to the evaluated intake were latter compared with those obtained by direct integration of the whole body measurements.

The CINDY code was used to fit the measured data to the predicted values according to the model selected.

The decrease of the whole body activity after the assumed stop of intake suggested a higher retention than the predicted by the standard ICRP 30 model for Caesium. As this publication states that, in some isolated cases, the biological half -life of the long-term retention can reach up to 200 days, the standard value of 110 days was changed to 200 days.

The graph in figure F4.3.1 shows the whole body measurements compared with the prediction of the standard ICRP 30 model and with the modified one.

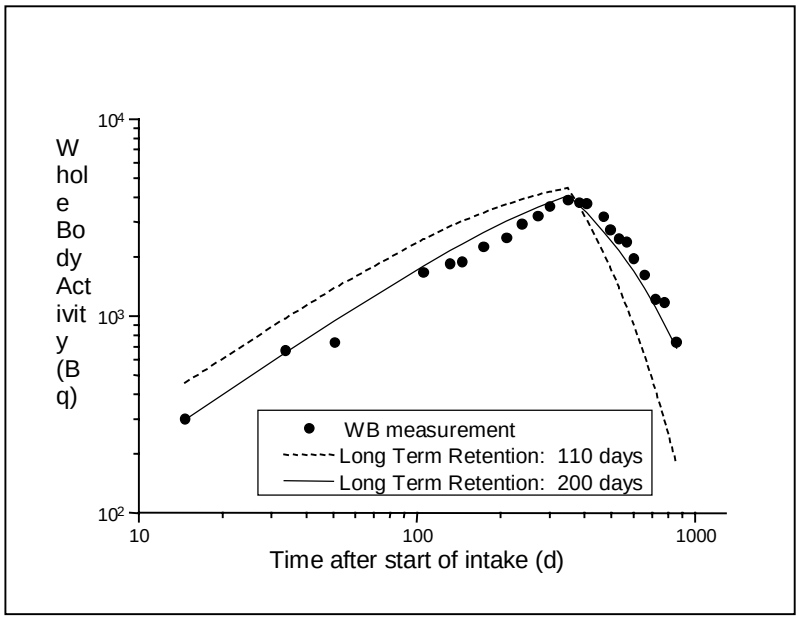


Fig. F4.3.1: Comparison of the whole body measurements with the model predictions

With this modified metabolic model, different dates for the beginning of the intake were tried, looking for the one that fits better to the data. The graph in figure F4.3.2 depicts, as an example, two attempts with different dates (15-05-86 and 25-05-86), and that in figure F4.3.3 shows the comparison of the whole body measurement with the model prediction for the finally chosen date (20-05-86).

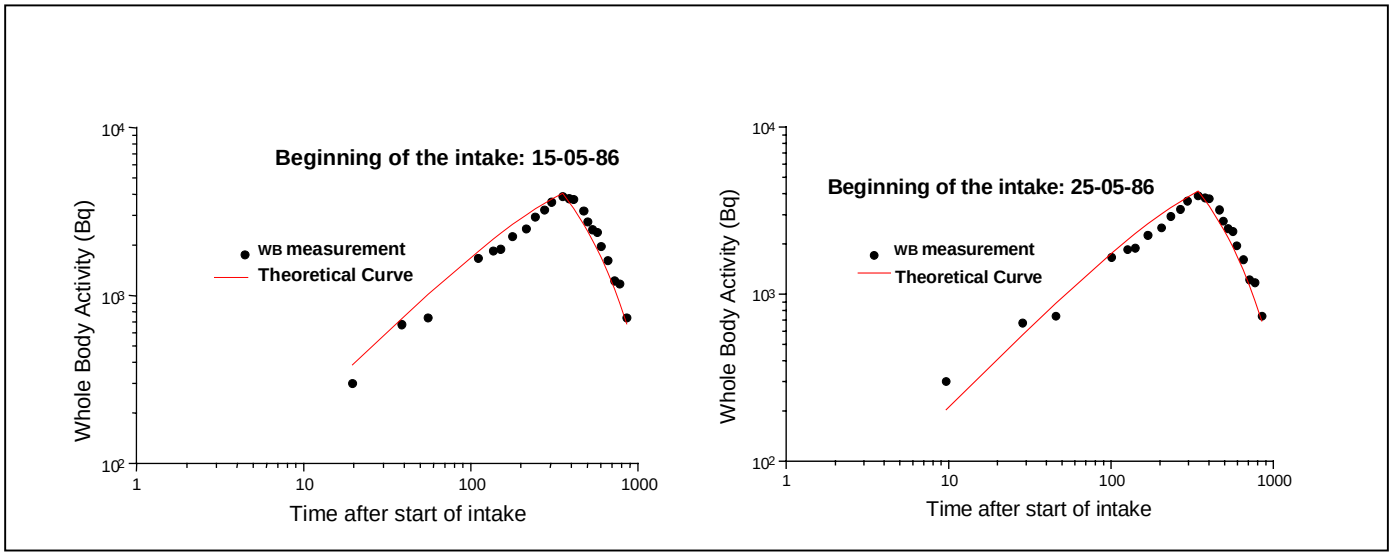


Fig. F4.3.2: Comparison of the whole body measurement with the model prediction for different dates for the beginning of intake (biological halflife of the long retention compartment 200 d)

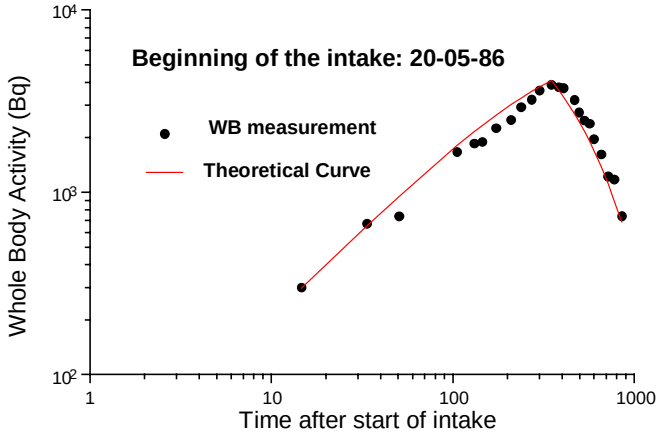


Fig. F4.3.3: Comparison of the whole body measurement with the model predictions for a continuous constant intake from May 20, 1986 to May 5, 1987 (biological halflife of the long retention compartment 200 d)

So, assuming a continuous constant intake by ingestion from May 20, 1986 to May 5, 1987 (350 days) and using the modified ICRP 30 metabolic model for Caesium (long-term retention: 200 days), the CINDY Code provides 23 Bq per day as estimated rate of intake, which results in a total intake of 8.05 kBq of ^{137}Cs.

Dose Assessment (via intake):

This rate of intake and the same metabolic models used for the intake assessment were the input to the CINDY Code for the dose assessment. The effective dose received by the subject in 1986 (E86) and 1987 (E87) respectively was estimated selecting the Calendar Year mode in the software. The Specified Time Period mode was used for estimating the committed effective dose (E(50)).

This provided dose assessments as below:

- 0.04 mSv received in 1986
- 0.11 mSv received in 1987
- a total committed effective dose of 0.2 mSv

Dose Assessment (directly from body burden):

As the pattern of intake assumed seems to be a rather fictitious one, not too much realistic, and as to a certain extent, the metabolic model was forced, an alternative dose assessment was made, directly from body burden measurements, in order to compare the obtained values.

The number of nuclear transformations in the source organ - that is 'total body' for caesium- was calculated using the software Origin 4.0 to graph the whole body activity measurements and to integrate it for the desired time intervals (1986 and 1987).

For estimating the committed effective dose E(50), the number of nuclear transformations that was added to that obtained by direct integration, was calculated according to the following expression:

$$739[\mathrm{Bq}]\cdot\int_{0}^{50a} e^{-\frac{\ln 2}{196d}t}\,dt = 1.8\cdot 10^{10}\ \text{transformations}$$

where :

- 739 Bq is the last measurement reported, and
- 196 days is the effective half-life of the long term retention.

The graph in figure F4.3.4 shows the number of nuclear transformations found in the desired time periods.

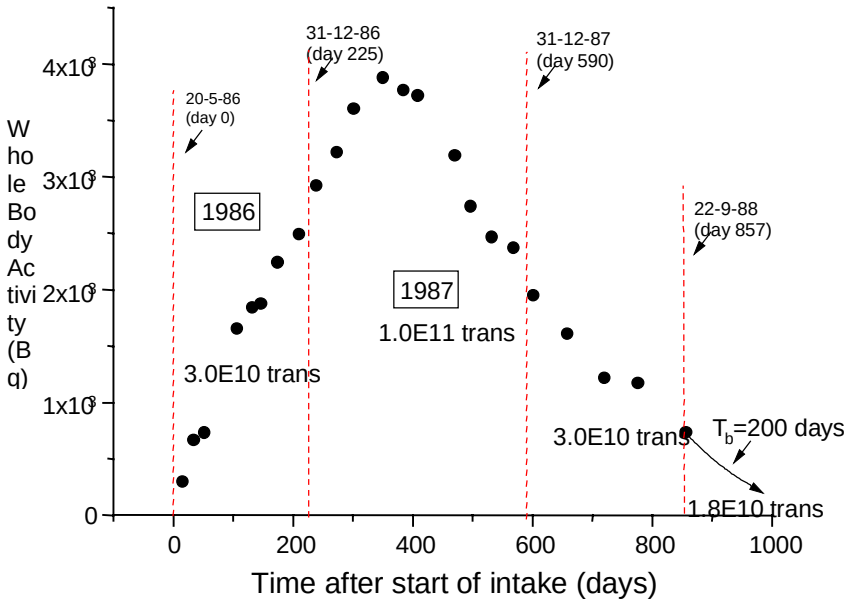


Fig. F4.3.4: Dose Assessment directly from body burden

Applying the Specific Effective Energy value, SEE(wb←wb), obtained from LUDEP 2.06 for the reference man, the effective doses obtained directly from body burden were as follows:

- 0.03 mSv received in 1986
- 0.10 mSv received in 1987
- a total committed effective dose of 0.18 mSv

As it was found that the values for the effective doses were almost the same for the two different approaches, it was decided to accept the simplified pattern of intake.

F4.4 Example II

Assessed by: *G. A. Roberts, Dounreay Approved Dosimetry Services, AEA Technology, UK*

Introduction:

The information provided for this case was that this was a member of the public who had received a continuous ingested intake of ^{137}Cs, the source of which was environmental contamination arising form the Chernobyl accident on 26 April 1986.

The individual had been whole body monitored at frequent intervals from June 1986 until September 1988. The results of this monitoring were provided; no measurement errors were reported and it was assumed that these errors would not be significant compared to the magnitude of the results.

The assessors were requested to calculate the intake from the accident until end of monitoring period, the effective dose received in 1986, the effective dose received in 1987 and the committed effective dose (arising from the intake received from accident until the end of the monitoring period).

Models and computer tools used for this assessment:

This case was assessed by the use of the current laboratory models, tools and methods. The models used were

- ICRP30 Gut model (with $f_1 = 1.0$);
- ICRP54 systemic retention model, and
- ICRP26 and ICRP30 (SEE values) for dose assessment.

The application of these models is performed by the use of a spreadsheet tool, which has been designed in-house by the laboratory and is employed for both intake and dose calculations. This spreadsheet provides solutions, in various graphical and numerical formats, to the formula:

$$\int_0^T \frac{dU(t)}{dt} \cdot f(T-t) \cdot dt$$

where

$\frac{dU(t)}{t}$ function defining rate of systemic uptake; and

$f(T-t)$ function defining systemic retention or excretion.

Use of spreadsheet for intake assessments: for calculating intake assessments the assessor is required to enter mathematical expressions corresponding to rate of systemic uptake and systemic retention or excretion (these expressions were derived from the ICRP30 gut model and ICRP54 systemic retention model respectively for this case). The measurement data set is entered and the assessor then enters a simple exposure scenario based on the case information available and by a crude interpretation of the measurement data set. In the above formula the first integral will provide predictive results for an acute intake; the second for a chronic intake (the third integral is not used for intake assessments).

The spreadsheet will provide indications of the 'goodness of fit' between the results predicted by the use of the model functions and exposure scenarios, and the measurement data set. These indications are provided by various statistical analyses and graphical representations, including chi-square test, cusum analysis and direct ratios of observed to predicted data. The quality of the 'fit' is determined by the assessor; if the fit is considered to be poor then the assessor may elect to amend either the exposure scenario or the model functions, or maybe both. This process continues until the assessor is satisfied he has a reasonable correlation between predicted and measured data; this may include the discarding of some data from the correlation.

Use of spreadsheet for dose assessments: when an intake has been calculated, the spreadsheet may be used to calculate the resultant received or committed dose. Expressions relating to the appropriate uptake and retention functions are entered together with the assessed intake and exposure scenario. The second integral of the above formula provides the number of transformations within a source organ from an acute intake; the third integral for a chronic intake. This is converted to dose by the use of Specific Effective Energy values and unit conversion factors.

Spreadsheet validation: the spreadsheet has been validated by comparison to ICRP54 curves and NRPB's BAP program for a variety of test cases.

Assessment procedures:

It is noted that intake assessments require a high degree of judgement on the part of the assessor. This includes adjudging the quality of the correlation between measured and predicted data, modifying exposure scenarios and model functions to obtain better correlation and also for deciding when certain measured data should not be included within the assessment. A quality assurance framework is required for the discharge of such 'expert judgement'; this should provide a measure of objectivity, consistency and accountability in the performance of assessments.

General Principles of Assessment: qualify before quantify: The laboratory operates a quality assurance framework to define the 'General Principles of Assessment'. The primary principle is that the measurement data set requires qualification before it can be used to provide quantifiable estimates of intake and dose. This means that the assessor needs to be able to explain the data in terms of exposure scenarios, model functions and treatment of uncertainties before the data should be used (or rejected) as part of an assessment.

General Principles of Assessment: defaults: The laboratory defines and provides validation for a range of defaults to be used as the starting point for any assessment. These defaults will include models, model parameters (eg lung absorption class), tools, methods and procedures. These defaults are always used unless there is case-specific information to do otherwise.

General Principles of Assessment: case-specific: it is often the case that the use of defaults, even when qualified by case-specific information, will not provide a reasonable qualification of the measurement data sets (allowing for known and recorded uncertainties in these data sets). A

structured approach is adopted to determine a reasonable qualification, as follows (in general order of precedence):

1. Modify intake magnitude and exposure scenario, limited by any constraints apparent from the case-specific information. If this fails to provide the desired qualification then

2. Modify model parameters (eg AMAD, gut uptake factors):

3. Identify any 'rogue' data within the data set – i.e. data that differs significantly from other data around the same time period.

4. Modify model functions.

5. Derive case-specific models.

The above points are presented in an approximate order of precedence; however, they should always be adopted within the context of any case-specific information available. These various actions should also be considered within the context of the ability to validate these modifications; it would not be meaningful to attempt to qualify the data set by means of an unqualified modification to a default model or rejection of a significant data point (for example). As a general rule multiple, independent, measurement data sets (urine, in-vivo etc) should be available before considering modifications to model parameters or functions; these multiple data sets will provide some degree of qualification for the modifications.

Intake assessment – Case 4:

The standard laboratory models, tools and procedures (discussed above) were used for the assessment of case 4. The first indications derived from the whole body monitor data (depicted in fig. F4.4.1) implied a chronic exposure extending for 450 days; it is assumed that this is a constant rate exposure, by application of laboratory default assumptions. The start of this exposure period is about 30 days after the Chernobyl accident, which may be considered a reasonable time delay to allow for ingress and transfer through the food chain.

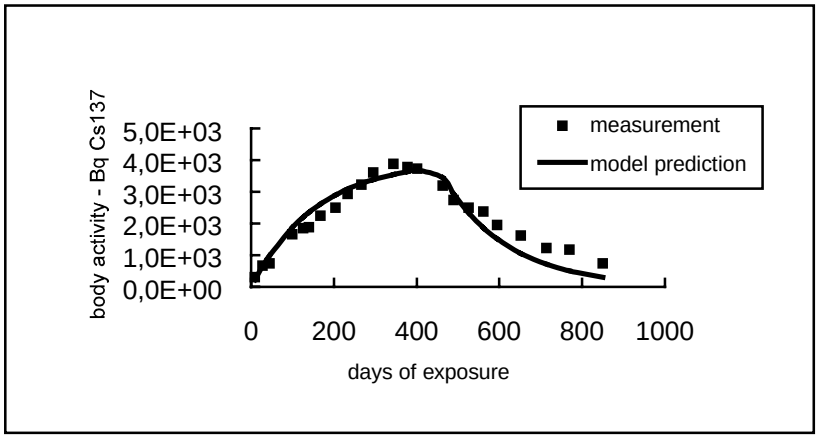


Fig. F4.4.1: Comparison of measurement with model prediction assuming one period of chronic ingestion

This first assessment attempt was able to produce a reasonable correlation to the first half of the data set, but tends to under-estimate the latter half. As defined in the 'general principles of assessment' (as discussed above) the first attempt to make a case-specific adjustment to the assessment is to modify the exposure scenario. The simplest adjustment is to include a second period of chronic exposure at much lower intake rate than the first. This second exposure period starts at the end of the first and continues (at constant rate) to the end of the monitoring period. As a qualification it maybe assumed that this period of reduced exposure might be due to either change of habit or diet, the consequence of the implementation of food controls or natural clearance from the food chain. There is no specific justification for this assumption from within the case information but it is not in conflict with the case information provided.

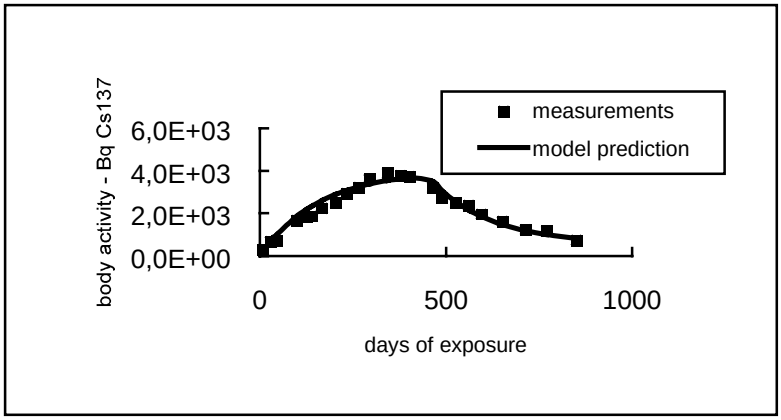


Fig. F4.4.2: Comparison of measurement with model prediction assuming two periods of chronic ingestion

The graph in figure F4.3.2 depicts this adjusted assessment, which now provides a reasonable correlation to the whole of the data set. This was therefore used as the basis for the assessment of intake, which is of a chronic ingested intake of

- 28 Bq ^{137}Cs per day from May 86 to August 87; and
- Bq ^{137}Cs per day from August 87 to September 88; providing
- total intake of 14.2 kBq ^{137}Cs.

Dose Assessment:

This intake and exposure scenario were input to the assessment spreadsheet, together with the same uptake and retention functions as used for the intake assessment. This spreadsheet (when applied for dose assessment) calculates the number of nuclear transformations within a source organ: for 137Cs the source organ is simply the 'total body' (ICRP30). By defining appropriate limits for the integrals within the spreadsheet this calculation can be performed for the desired time periods which, in this case, were for 1986 and 1987 separately, and for the fifty-years after the start of the intake. The dose for each relevant 'target organ' (as defined in ICRP30) is then calculated by applying the appropriate Specific Effective Energy values and unit conversion factors (from MeV/g to J/kg). This provided dose assessments as below: -

- 0.04 mSv received in 1986:
- 0.07 mSv received in 1987: and
- a total committed effective dose equivalent of 0.2 mSv.

F5 Enhanced intake of natural radioactivity

F5.1 Case description

Main characteristics

- Non radiation worker
- Real case
- Inhalation (enhanced natural radioactivity at the working place)
- Air monitoring (air activity concentration and particle size measurement)

F5.1.1 The event

F5.1.1.1 *Description of the working area*
The factory produces electro-fused refractory blocks using Zircon sands in the construction of melting ovens for glass.

F5.1.1.2 *Characteristics of work*
The Zircon sand is stored in large reinforced concrete tanks. It is mixed with alumina, sodium carbonate before being melted in the oven. The molten material is poured into moulds and the finished blocks are left to cool for 15 to 20 days in the cooling area. Then they are moved to another room where they are sand-blasted, ground, polished with emery, finish ground and finally cut. The accurate assembly of all components of each oven is then checked in the pre-assembly area.

F5.1.1.3 *Reasons for monitoring; initiating event*
Significant external gamma dose rate was measured in the working area. As a consequence it was decided to investigate the exposure conditions of workers.

F5.1.1.4 *Actions taken*
None

F5.1.2 Additional information

F5.1.2.1 *Air monitoring*
In the area under investigation an aerosol sampler, a cascade impactor and a dicotomous sampler have been applied for measurement of the room air activity concentration and for characterisation of the particle size distribution, respectively.

F5.1.2.2 *Chemical form*
Zircon sands are characterised by high concentration of $ZrSiO_4$ and ZrO_2 . It is well known that this kind of sand contains significant activity of uranium and thorium and their daughter products.

F5.1.2.3 *Physical characteristics, particle size*
The cascade impactor measurement showed two modes (fractions) of the particle distribution by mass. These two modes were fitted by means of two log-normal probability density functions, the parameters of which are listed in the table below (MMAD = mass median aerodynamic diameter).

Total dust [mg/m^3]	First mode			Second mode		
	Total mass fraction [%]	MMAD [μm]	Geom. Standard deviation	Total mass fraction [%]	MMAD [μm]	Geom. standard deviation
0.84	19.3	0.27	2.0	80.7	10.3	2.5

The first mode is mainly due to the thermal treatment of the sand and the second due to the mechanical treatment. Thus, it may be assumed that the composition of the particles of the second mode is the same as that of the Zircon sand given in the table below (uncertainties given in terms of one standard deviation).

Activity concentration of Zircon sand [Bq/kg]						
^{235}U	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{232}Th	^{228}Th
135±6	2800±60	2810±100	2800±30	2730±240	678±19	682±18

The evaluation of the time dependence of the alpha activity on the total filter revealed two main components, which may be attributed to ^{210}Po and the sum of ^{238}U,^{235}U and ^{232}Th and daughters as shown in the following table.

Total alpha activity concentration [Bq/m^3]	
^{210}Po	^{238}U,^{235}U and ^{232}Th and daughters
0.43	0.024

There is no evidence for significant releases of Radon during heating of the sand and so it may be assumed that the natural families are in equilibrium from ^{238}U to ^{210}Pb, from ^{235}U to ^{207}Tl and from ^{232}Th to ^{208}Tl, respectively.

The investigation of the dicotomous sample revealed the partitioning shown in the table below.

	Fraction of activity [%]	
	^{238}U,^{235}U and ^{232}Th and daughters	^{210}Po
First mode	19.3	72.1
Second mode	80.7	27.9

For this investigation it may be assumed that the parameters describing the particle distribution in terms of activity are identical to those describing the particle distribution in terms of mass for both modes.

F5.1.2.4 *Nose swab, bronchial slime or similar*
Not applicable
F5.1.2.5 *Non removable skin contamination*
None
F5.1.2.6 *Wound site activity*
None
F5.1.2.7 *Any intervention used (blocking, chelating, etc.)*
None

F5.1.3 Personal Data

F5.1.3.1 *Sex*
Male
F5.1.3.2 *Age (at the year of the incident)*
30 y
F5.1.3.3 *Weight*
75 kg

F5.1.4 Body monitoring data

F5.1.4.1 *Whole body activity measurements*
none

F5.1.4.2 *Organ activity measurement*
none

F5.1.5 Excretion monitoring data

F5.1.5.1 *Urine activity measurement*
none

F5.1.5.2 *Feces activity measurement*
none

F5.1.6 Other comments relevant for intake and dose estimation
For evaluation of the case the following assumptions should be made :
Exposure time 8 h/d for 250 d/y.
Breathing rate 1.2 m^3/h
Non-smoker subject

F5.1.7 Results

Annual intake [Bq]			
^{210}Po	^{238}U	^{235}U	^{232}Th

Committed effective dose E(50) due to one year of exposure [μSv]			
^{210}Po	^{238}U + daughters	^{235}U + daughters	^{232}Th + daughters

Additional comments

F5.1.7.1 Computer code(s) applied
F5.1.7.2 Model(s) applied
F5.1.7.2.1 Standard ICRP models
F5.1.7.2.1.1 Type of models
F5.1.7.2.1.2 Model parameters (inhalation class or clearance type, AMAD etc.)
F5.1.7.2.2 Other models
F5.1.7.2.2.1 Reason for applying other models
F5.1.7.2.2.2 Type of models
F5.1.7.2.2.3 Characteristic parameters
F.5.1.7.3 Data used for calculation (all data or selected data)
A.5.1.7.4 Additional information

F5.2 Answers of the participants

Table F5.2.1: Results (outliers in shadow)

Participant ID	Annual intake (Bq)				E(50) (μSv)			
	^{210}Po	^{238}U	^{235}U	^{232}Th	^{210}Po	^{238}U + daughters	^{235}U + daughters	^{232}Th + daughters
1	1032	44.61	2.15	10.83	3353	2418	117	659
4	1030	5.6	0.3	1.4	4240	290	14	80
5	1030	50.8	0.615	6.2	3178	490	12.1	381
6	1032	5.6	0.27	1.4	4310	407	19.7	110
7	1032	5.85	0.28	1.42	4243	304	14.6	82.9
14	1032	5.6	0.27	1.37	3100	290	14	80
17	1032	6.58	0.32	1.61	3093	327	17	94
18	1032	5.64	0.27	1.37	2476	388.7	18.6	81.1
20	1038	5.6	0.27	1.36	2860	125	1.7	64
21	1000	6.6	0.3	1.6	3000	350	15	100
25	1000	13	0.62	3.1	2900	980	11	700
29	1000	5.6	0.3	1.4	3700	127	20	57
30	1032	13	0.6	3	2167	1000	10	710
33	1032	5.95	0.287	1.44	910	360	4.8	230
34	1030	6.55	0.32	1.59	3350	340	8	97
39	1032	12.8	0.62	3.1	4000	630	4.3	17.1
42	1032	5.5	0.24	1.92	1930	77	3.5	266
46	1032	13	0.6	3	4000	613	30	169

Table F5.2.1 (continued): Results (outliers in shadow)

Participant ID	Annual intake (Bq)				E(50) (μSv)			
	^{210}Po	^{238}U	^{235}U	^{232}Th	^{210}Po	^{238}U + daughters	^{235}U + daughters	^{232}Th + daughters
48	1032	5.65	0.273	1.364	2860	414	41	312
49	1032	5.7	0.25	1.36	3038	80.5	50.3	775
GM	1027	6.98	0.35	1.72	3180	355	13.7	157
GSD	1.01	1.41	1.43	1.39	1.25	2.31	2.62	2.80
AM	1027	7.43	0.37	1.82	3252	501	21.3	253
ASD	12	3.06	0.15	0.69	689	517	25.6	253
Minimum	1000	5.5	0.24	1.36	910	77	1.7	17.1
Maximum	1038	50.8	2.15	10.83	4310	2418	117	775

Table F5.2.2: Model(s) applied

Participant ID	Respiratory tract	Systemic biokinetics	Tissue weighting factor	Dose coefficient (Sv Bq^{-1})
1	ICRP 66			
4	ICRP 66	ICRP 30/54		LUDEP
5	ICRP 66	ICRP 67/69	ICRP 60	
6	ICRP 66	ICRP 30	ICRP 60	LUDEP
7	ICRP 66	ICRP 30	ICRP 60	
14	ICRP 66	ICRP 30		
17	ICRP 66	ICRP 30	ICRP 60	
18	ICRP 66	ICRP 30		
20	ICRP 66	ICRP 78		IAEA BSS115
21	ICRP 66	ICRP 30		
25	ICRP 30	ICRP 30	ICRP 26	
29	ICRP 66	ICRP 67	ICRP 60	IDSS
30	ICRP 30	ICRP 30	ICRP 26	
33	ICRP 30	ICRP 30	ICRP 26	
34	ICRP 66	ICRP 30	ICRP 60	
39	ICRP 66	ICRP 30		
42	ICRP 30	ICRP 54	ICRP 26	
46	ICRP 66	ICRP 30		
48	ICRP 30	ICRP 30		
49	ICRP 30	ICRP 30		

Table F5.2.3: Data handling

Participant ID	AMAD 1st mode (μm)	AMAD 2nd mode (μm)	Absorption type or inhalation class			Data used for calculation
			Po	U	Th	
1						
4	0.27	10.3	S	S	S	
5	0.27	10.3	M	M	S	
6	0.27	10.3	M	S	S	all
7	0.27	10.3	S	S	S	all
14	0.27	10.3	M	S	S	all

Table F.5.2.3 (continued): Data handling

Participant ID	AMAD 1st mode (μm)	AMAD 2nd mode (μm)	Absorption type or inhalation class			Data used for calculation
			Po	U	Th	
17	0.27	10.3	M	S	S	all
18						
20	1	5	F	S	S	
21	0.27	10.3	M	S	S	all
25	0.27	10	W	Y	Y	all
29	0.27	10.3	S	S	S	all
30	0.27 (1 for ^{210}Po)	10	W	Y	Y	all
33	0.27	10	W	Y	Y	all
34	0.27	10.3	M	S	S	all
39	0.27	10.3				
42	0.3	10	Y	Y	Y	all
46	0.27	10.3	W	Y	Y	all
48	0.27	10.3	W	Y	Y	all
49	0.3	10	W	W	W	

Table F5.2.4: Additional information

Participant ID	Additional information
1	
4	It is assumed that all daughters are present at the time of inhalation.
5	The progeny nuclides were assumed to follow biokinetic model and solubility of the parents. 222-Rn was assumed to leave the body after formation and before decay so it is not contributing to the dose. The concentration of the zircon sand was assumed to apply to both modes of the dust.
6	The fraction of activities in the two aerosol modes was accepted as given in the case description.
7	
14	
17	
18	
20	
21	
25	An alternative approach has been made including other daughter products; this approach resulted in lower values for the intake and doses of U and Th (about 50 % of the values given in the table).
29	The assumption about insignificant release of Radon is unrealistic. Daughter products are considered in the human body and in the sand as well.
30	The CEDE value for 210-Po refers to 1 μm AMAD.
33	
34	
39	
42	Particle size correction was made in accordance with ICRP30.
46	An inhalation of 2400 Bq over 250 d was assumed.
48	Particle size correction was made in accordance with ICRP30.
49	Particle size correction was made in accordance with ICRP30.

F5.3 Example I

Assessed by: *G. H. Kramer, Human Monitoring Laboratory, Radiation Protection Bureau, Ottawa, Ontario, Canada. Gary_H_Kramer@hc-sc.gc.ca*
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Introduction:

This was a real case of inhalation of enhanced natural radioactivity at the work place. The location was a factory that produces electro-fused refractory blocks using Zircon sands in the construction of melting ovens for glass.

The assessors were asked to estimate the annual intake of radioactivity of ^{210}Po, ^{238}U, ^{235}U, and ^{232}Th ,and the resulting effective doses of ^{210}Po, ^{238}U + daughters, ^{235}U + daughters, and ^{232}Th + daughters due to one year of exposure. These estimates were made based on air monitoring data with the following information being provided:

- cascade impactor data with bimodal particle size data and fraction of activity in each partition
- activity concentration of the radionuclides in the Zircon sands
- total alpha activity air concentration (^{210}Po and ^{238}U, ^{235}U, and ^{232}Th)
- daughters were in equilibrium from ^{238}U to ^{210}Pb, ^{235}U to ^{207}Tl, and ^{232}Th to ^{208}Tl.
- exposure time was 8h/d for 250 d/y
- breathing rate was 1.2 m^3/h
- the subject was a non-smoker

For the purpose of this analysis it was further assumed that for the purpose of the dose estimate the intake was acute, the hypothetical subject was an adult male standard worker doing light exercise, the inhaled material was Type S, and a volume seeker.

Models and computer tools used for this assessment:

This case was assessed using LUDEP 2.04 (dosimetry code) and EXCEL97 (spreadsheet). The models used by the dosimetry code were

- ICRP30 metabolic models
- ICRP66 lung model

Use of spreadsheet for intake assessments: The spreadsheet was set up to calculate the intakes of the radionuclides prior to dose assessment. The analysis took two slightly different approaches as described below.

Assessment procedures:

In this case there is no actual bioassay data to compare to model predictions. Normally intake assessments require a high degree of judgement to assess the degree of the goodness of fit between measured and predicted data. This may then involve several iterations that modify exposure scenarios and model functions to obtain better agreement. It may also include rejection of certain bioassay results that may be inaccurate due to sample contamination, blunders, or incorrect application of minimum detectable activity concepts.

The assessment procedure for this case was, therefore, straightforward. Default values (intake was acute, the material was Type S, and a volume seeker) have been used for all evaluations where information was not provided within the case to the contrary.

A judgement was made to use the total activity air concentration for calculation of intake values. An alternative method (and not used) would have been to use the total dust air concentration given with the cascade impactor data combined with the specific activity values to obtain intake estimates for ^{238}U, ^{235}U and ^{232}Th. This calculation route would have resulted in intake values that are a factor of approximately 2.3 lower than the results calculated below. The impact of this factor is discussed later.

Intake assessment:

The standard laboratory models, tools, procedures, and assumptions (discussed above) were used for the assessment of case 5.

Intake of ^{210}Po: The total alpha activity of ^{210}Po was given was 0.43 Bq/m^3. The intake is, therefore, simply the product of the air concentration multiplied by the total volume of air breathed in one year at the work place (2400 m^3 that is obtained from exposure time multiplied by breathing rate). Thus, the total intake was found to be 1032 Bq. This amount was then partitioned according to the particle size information that gave the fraction of activity in each part of the dichotomous sample.

First mode (AMAD of 0.27 μm): 0.721 x 1032 Bq = 744 Bq.
Second mode (AMAD of 10.3 μm): 0.279 x 1032 = 288 Bq.

These amounts were used as intake values in LUDEP.

Intake of ^{238}U, ^{235}U, and ^{232}Th: The air concentration of these radionuclides was not measured directly (only the total alpha activity was measured). Their intakes were estimated from the specific activity data, the total volume of air breathed and the total alpha activity. It was assumed that the total alpha air concentration applied to only ^{235}U, ^{238}U, ^{234}U, ^{230} Th, ^{226}Ra, ^{232}Th, and ^{228}Th. Daughters in radioactive equilibrium, other than those listed immediately below, were not included as a modifier.

Specific activity Bq/kg							
^{235}U	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{232}Th	^{228}Th	Total
135	2800	2810	2800	2730	678	682	12635

Intake = specific activity x alpha air concentration x total volume breathed. For example, the intake of ^{238}U is given by (2800 x 0.024 x 2400)/12635 = 12.76 Bq. The intakes of ^{235}U and ^{232}Th are 0.61 Bq and 3.09 Bq respectively. These intakes must be partitioned according to the particle size information that gave the mass fraction of these radionuclides in each part of the dichotomous sample. Thus:

Mass fraction	AMAD (μm)	GSD	^{238}U (Bq)	^{235}U (Bq)	^{232}Th (Bq)
0.19	0.27	2	2.46	0.44	0.60
0.81	10.3	2.5	10.30	0.17	2.49

These amounts were used as intake values in LUDEP.

Dose Assessment:

Each of the eight intake and exposure scenarios were run using LUDEP, the internal dosimetry code. All nuclides were set to inhalation Type S, and volume seeker for the metabolic model. In the cases of ^{238}U, ^{235}U and ^{232}Th the daughters were set to equilibrium values using the „merge“ option. The AMAD values and GSD values were set within the code and the dose calculated over 50 years

	E(50) from LUDEP (µSv)			
	^{210}Po	^{238}U	^{235}U	^{232}Th
Fraction 1	3540	260	45.7	76.8
Fraction 2	460	370	6.2	93.2
Total	4000	630	51.9	170
Grand Total: 4.85 mSv				

Recall that the alternate approach would give the intakes, and effective doses, of ^{238}U, ^{235}U and ^{232}Th a factor of approximately 2.3 lower than shown above. The dose from these nuclides totals 0.85 mSv in the table above. This value would be reduced to about 0.4 if the alternate approach were used. Both are below the public dose limit (1 mSv) and is no cause for concern.

The alternate approach does not apply to ^{210}Po, which so happens to be the dominant component of internal dose. The internal dose resulting from an intake of this radionuclide is four times the public dose limit and indicates that protective measures (including ongoing air monitoring) must be taken for workers in this plant.

F5.4 Example II

Assessed by: *K. S. Thind, Ontario Power Generation, 1549 Victoria St.East., Whitby, Ontario, Canada L1N 9E3*

Introduction

The case description consisted of four pages of information on a real case involving a factory that processes Zircon sands for construction of melting ovens for glass. The enhanced levels of activity associated with the Zircon sands consisted of ^{232}Th, ^{235}U and ^{238}U and their progeny radionuclides. In the production of melting ovens there are several processes and operations such as mixing, melting, pouring into moulds, sand blasting, grinding and polishing which have the potential for generation of significant airborne contamination. According to the information given, an external radiation survey of the work area showed levels significantly above background, which triggered the air monitoring campaign.

Data Description

Air monitoring was done using an aerosol sampler (likely a total dust sampler), a cascade impactor for particle size characterization, and a dichotomous sampler.

The cascade impactor data showed a bimodal particle size distribution. The total mass fraction, mass median aerodynamic Diameter (MMAD) and geometric standard deviation (GSD) for both modes are given.

A total dust concentration of 0.84 mg/m^3 in the work area is given.

Activity concentration data for seven radionuclides in the Zircon sand is given.

A gross alpha activity measurement on the total dust filter as a function of time showed that this activity may be attributable to two fractions: ^{210}Po and the sum of ^{232}Th, ^{235}U and ^{238}U and their progeny radionuclides. The ^{210}Po fraction had a concentration of 0.43 Bq/m^3 while the other fraction had a concentration of 0.024 Bq/m^3.

The dichotomous sampler data provided information on the fraction of activity attributable to ^{210}Po and the sum of ^{232}Th , ^{235}U and ^{238}U and their progeny radionuclides for the first and second particle size modes.

The personal data suggests that workers at the factory are male with an average age of 30 y and body weight of 75 kg.

Required Calculations

Inter-comparison participants were required to calculate the following:

- Annual Intake (in units of Bq) for: ^{210}Po, ^{232}Th, ^{235}U and ^{238}U
- Committed Effective Dose, e (50), (in units of μSv), due to one year of exposure for: ^{210}Po, ^{232}Th + progeny, ^{235}U+ progeny, and ^{238}U + progeny.

A Priori Assumptions

The following assumptions were given as part of the case description:

- The radionuclide composition of particles in the second mode is the same as the radionuclide composition in the Zircon sand as the second mode is attributable to mechanical treatment of the sand.
- The particle size parameters given in terms of mass (MMAD) are the identical to those in terms of activity (AMAD) for both modes.
- There is secular equilibrium in the natural radioactivity series with parent radionuclides: ^{232}Th, ^{235}U and
- ^{238}U(but not including ^{210}Po).
- For intake assessment the exposure time is given to be 8 h/d for 250 d/y. The breathing rate of 1.2 m^3h^{-1} for a non-smoker is to be used.

Additional Assumptions Required for Intake and Dose Assessment

- The male worker is equivalent to Reference Man
- The male worker's occupational task consists of light work or exercise.
- The radionuclide composition of particles in the first mode is the same as the radionuclide composition in the Zircon sand.
- From the case description it is not clear whether the total dust sampler is an area (static) or personal sampler. Personal air sampling is generally preferred over area sampling. It is assumed that the data reflects personal air sampling.

Method for calculating the annual intake for ^{210}Po, ^{232}Th, ^{235}U and ^{238}U

The total dust aerosol sampler shows an air concentration of 0.024 Bq/m^3 attributable to ^{232}Th, ^{235}U and ^{238}U and their progeny. From the radioactivity concentration data for Zircon sand, the individual activity fractions were calculated. Multiplication of the individual activity fractions of ^{232}Th, ^{235}U and ^{238}U with the air concentration value of 0.024 Bq/m^3 gives the activity concentration values for these radionuclides. The resulting air concentrations for these three radionuclides were further subdivided into air concentrations present in the first and second aerosol mode using activity fractions 0.193 and 0.807 respectively. The annual intake for each aerosol mode was calculated using a yearly sampling volume of $1.2\ m^3h^{-1} \times 8\ h\ d^{-1} \times 250\ d\ y^{-1} = 2400\ m^3\ y^{-1}$. For the sake of completeness these calculations were also performed for ^{230}Th, ^{228}Th, ^{234}U and ^{226}Ra.

The total dust aerosol sampler shows an air concentration of 0.43 Bq/m^3 attributable to ^{210}Po. The ^{210}Po air concentrations present in the first and second aerosol mode were calculated using activity fractions 0.721 and 0.279 respectively. The annual intake for each aerosol mode was calculated as described in the previous paragraph.

The intake contributions from both modes were summed to calculate the total annual intakes for the various radionuclides.

The foregoing calculations were performed using the Microsoft Excel spreadsheet program. Tables F5.4.1 and F5.4.2 summarize the various individual steps.

Table F5.4.1: Calculation of Annual Intakes for ^{232}Th, ^{235}U and ^{238}U and progeny

Radio-nuclides	Activity Bq/kg	1σ	Activity Composition %	Alpha activity Conc. From dust filter data Bq/m^3	AMAD 0.27 μm First Mode Bq/m^3	AMAD 10.3 μm Second Mode Bq/m^3	Intake First Mode Bq	Intake Second Mode Bq
^{235}U	135	6	1.068460	0.000256431	4.94911E-05	0.0002069	0.11877863	0.496654689
^{238}U	2800	60	22.160664	0.00531856	0.00102648	0.0042920	2.46355678	10.30098615
^{234}U	2810	100	22.239810	0.005337554	0.001030148	0.0043074	2.47235520	10.33777539
^{230}Th	2800	30	22.160664	0.00531856	0.00102648	0.0042920	2.46355678	10.30098615
^{226}Ra	2730	240	21.606648	0.005185596	0.00100082	0.0041847	2.40196786	10.0434615
^{232}Th	678	19	5.366046	0.001287851	0.00024855	0.0010392	0.59653267	2.494310218
^{228}Th	682	18	5.397704	0.001295449	0.00025002	0.0010454	0.60005204	2.509025912

Table F5.4.2: Calculation of Annual Intake for ^{210}Po

^{210}Po Bq/m^3	First Mode Bq/m^3	Second Mode Bq/m^3	Intake First Mode Bq	Intake Second Mode Bq
0.43	0.31	0.12	744.072	287.928

Method for calculating the committed effective dose e (50) for ^{210}Po, ^{232}Th, ^{235}U and ^{238}U

This intercomparison exercise occurred at a time when the ICRP had published new recommendations on lung and metabolic (ICRP Publications 66, 67, 68, 69, 72) models but the necessary software that could implement these recommendations in their entirety were not available to this dose assessor. A decision had to be made between using the old lung model (ICRP Publication 30) and metabolic models (ICRP Publications 30 and 54), and a combination of the old metabolic models and new lung model (ICRP Publication 66). The decision to assess the committed effective dose was based on the intent to use as many of the latest ICRP recommendations as possible taking into account the availability of the software codes. The code LUDEP v2.05 was recently purchased and this case was a good opportunity to test it. LUDEP v2.05 implements fully the new ICRP lung model and covers the full range of aerosol particle sizes of interest. However this version of the code restricted the user to the older metabolic models (Publication 30 and 54). The merge option permits taking into account the dose contributions from progeny radionuclides.

For this case the committed effective dose, e (50), due to one year of exposure needs to be calculated. Options H and I of the intake regime of LUDEP v2.05 were used and an air concentration of 1 Bq/m^3 and exposure time of 2000 h were entered. Standard occupational exposure conditions were set on the code: adult male, with a light work regimen. The code automatically calculated an annual intake of 2400 Bq. The merge option was invoked for ^{232}Th, ^{235}U and ^{238}U. Separate runs were made for the two aerosol modes characterized by AMAD values of 0.27 μm and 10.3 μm. The

expressed output was in units of Sv per 2400 Bq intake. The required e (50) values were calculated by scaling the output values to the calculated annual intake values for the two modes (Table 1) and performing a summation. This calculation was set up on a Microsoft Excel spreadsheet as shown in Table F5.4.3. All calculations were first run to give the answer in units of Sv. In the final step a conversion to μSv was made to avoid unit conversion errors.

Table 5.4.3. Calculation of committed effective dose e (50)

Radionuclides	Bq (0.27 μm) Intake (Bq)	Bq (10.3 μm) Intake (Bq)	Sv/2400Bq (0.27 μm)	Sv/2400Bq (10.3 μm)	e(50) Sv	e(50) μSv
^{235}U	0.118	0.494	2.52E-01	8.78E-02	3.04343E-05	30.43426667
^{238}U	2.504	10.472	2.42E-01	8.26E-02	0.000613281	613.2812
^{232}Th	0.594	2.482	3.07E-01	8.98E-02	0.000168931	168.9311917
^{210}Po	744	288	1.14E-02	3.83E-03	0.00400016	4000.16

Reported Results

From Tables F5.4.1, F5.4.2 and F5.4.3 the annual intake and committed effective dose values were reported in the format requested by the intercomparison exercise:

Table F5.4.4. Results in terms of annual intake

Annual Intake (Bq)			
^{210}Po	^{238}U	^{235}U	^{232}Th
1032	13	0.6	3

Table F5.4.5. Results in terms of committed effective dose e (50)

Committed Effective Dose e (50) [μSv] due to 1 y exposure			
^{210}Po	^{238}U	^{235}U	^{232}Th
4000	613	30	169

F6 Single intake of 239Pu

F6.1 Case description

Main characteristics

- Radiation worker
- Real case
- Inhalation
- Urine and faeces measurement

F6.1.1 The event

F6.1.1.1 *Description of the working area*
Radiochemical laboratory for the development of advanced nuclear fuels in a nuclear research centre

F6.1.1.2 *Characteristics of work*
In the laboratory nuclear fuel micro-spheres had been produced in a glove box using a special gelling technique. The wastewater resulting from this technique was routinely collected and evaporated in the box. The residual waste was transferred into a second glove box for further evaporation and disposal.

F6.1.1.3 *Reasons for monitoring; initiating event*
On 24.05.83 at 4.15 p.m. there was an explosion in the second glove box during evaporation of 3 l waste as a consequence of an unexpected exothermic reaction. The pressure of the explosion destroyed the gloves. Two persons working at the first box left the laboratory immediately after the explosion. However, they were strongly contaminated at face, hairs and clothes**.**

F6.1.1.4 *Actions taken*
The two directly involved persons (subjects A and B) were decontaminated in the radiation protection unit of the research centre. Nose swabs and also bronchial slime samples were taken from subject A**.**

F6.1.2 Additional information

F6.1.2.1 *Air monitoring*
There were stationary room air samplers.

F6.1.2.2 *Chemical form*
Uranium/Plutonium hydroxide gel in washing water containing about 10 % ammonium nitrate and about 3.5 % hexamethylentetramine

F6.1.2.3 *Physical characteristics, particle size*
The diameter of the plutonium containing particles is supposed to be between 3 and 40 μm according to scanning electron microscopy and qualitative X-ray analyses of dust samples from the laboratory.

F6.1.2.4 *Nose swab, bronchial slime or similar*
The nose swab of subject A contained 5.5 kBq ^{239}Pu and the bronchial slime 1.4 kBq ^{239}Pu.

F6.1.2.5 *Non removable skin contamination*
No data

F6.1.2.6 *Wound site activity*
None

F6.1.2.7 *Any intervention used (blocking, chelating, etc.)*
None

F6.1.3 Personal Data

F6.1.3.1 *Sex*
Male (subject A and B)

F6.1.3.2 *Age (at the year of intake)*
26 years (subject A)
30 years (subject B)

F6.1.3.3 *Weight*
80 kg (subject A)
70 kg (subject B)

F6.1.4 Body monitoring data

F6.1.4.1 *Whole body activity measurements*
None

F6.1.4.2 *Organ activity measurement*
None

F6.1.5 Excretion monitoring data

F6.1.5.1 *Urine activity measurement*
The results of urine activity measurements are given in the table below.

Date	Daily excretion rate of ^{239}Pu [mBq/d]	
	Subject A	Subject B
25.05.83		3.7
26.05.83	41	
07.06.83	4.7	1.6
14.06.83	3.7	
21.11.83		1.2
20.01.85	2.9	< 1.0
27.08.88	5.9	
11.02.89	6.2	
25.04.90	6.0	2.0
25.05.91	4.1	

F6.1.5.2 *Faeces activity measurement*

The results of faeces activity measurements are given in the table below.

Date	Daily excretion rate of ^{239}Pu [mBq/d]	
	Subject A	Subject B
25.05.83	5200	1700
26.05.83		1000
27.05.83	440	
06.06.83		0.073
23.06.83	0.67	
30.06.83		0.083
07.07.83	0.21	
21.11.83	0.42	
27.05.84		0.087
03.05.86		0.0021
24.04.90	0.031	
25.05.91	0.012	0.0039

F6.1.6 Other comments relevant for intake and dose estimation

F6.1.7 Results

	Total intake of ^{239}Pu [Bq]			Committed effective dose due to total intake of ^{239}Pu [mSv]		
	Based on urine	Based on faeces	best estimate	based on urine	Based on faeces	best estimate
Subject A						
Subject B						

Additional comments

F6.1.7.1 Computer code(s) applied
F6.1.7.2 Model(s) applied
- F6.1.7.2.1 Standard ICRP models
  - F6.1.7.2.1.1 Type of models
  - F6.1.7.2.1.2 Model parameters (inhalation class or clearance type, AMAD etc.)
- F6.1.7.2.2 Other models
  - F6.1.7.2.2.1 Reason for applying other models
  - F6.1.7.2.2.2 Type of models
  - A6.1.7.2.2.3 Characteristic parameters

F6.1.7.3 Data used for calculation (all data or selected data)
F6.1.7.4 Additional information

F6.2 Answers of the participants

Table F6.2.1: Results for Subject A (outliers in shadow)

Participant ID	Total intake of ^{239}Pu (Bq)			Committed effective dose due to total intake (mSv)		
	Based on urine	Based on faeces	Best estimate	Based on urine	Based on faeces	Best estimate
2	6000	5000	6000	486	405	486
4	36400	33000	36400	146	132	146
5	29000	6300	13000	240	52	110
7	48400	5230	48400	418.5	45.2	418.5
8	5300	18000	5300	44	150	44
9	15000	19000	16000	240	320	270
10	2917	6215	3375	275	586	318
13	120	30	120	600	150	600
14	53400	33000	49000	323	200	300
15	35000	30000	35000	300	93	300
17	46200	28400	46200	400	246	400
20	No data	15000	15000	No data	1220	1220
21	50000	30000	40000	No data	No data	600
24	1950	12700	12700	214	1397	1397
25	6500	9300	6500	230	330	270
27	72000	64000	69000	8600	7700	7600
28	8667	7548	8108	71.9	62.6	67.3
29	60000	32000	46000	184	98	141
30	3400	20000	20000	240	No data	240
31	35000	52000	35000	290.5	No data	290.5
32	0.0011	82.3	82.3	0.0000109	0.817	0.817
33	5300	3950	4600	430	320	375
34	36900	30900	30900	319	267	267
37	970	1170	1100	31	37	35
38	1700	18000	9900	14	150	80
39	475	6200	6200	17	224	224
41	12000	18000	15000	300	450	380
42	5746	3755	5746	465	304	465
44	29000	6300	6300	290	63	63
46	43958	28301	43958	272	175	272
47	47000	26000	36000	251	140	200
48	3210	13420	13420	143	140	140
49	69	57680	57680	9.7	8.075	8.075
GM	12241	15803	17388	288	188	240
GSD	4.10	2.29	2.47	1.44	2.49	2.4
AM	24186	21307	24690	307	287	337
ASD	21760	16006	18922	113	324	306
Median	15000	18000	15500	290	175	271
Minimum	0.0011	30	82.3	0.0000109	0.817	0.817
Maximum	72000	64000	69000	8600	7700	7600

Table F6.2.2: Results for Subject A based on the old ICRP models (outliers in shadow)

Participant ID	Total intake of ^{239}Pu (Bq)			Committed effective dose due to total intake (mSv)		
	Based on urine	Based on faeces	Best estimate	Based on urine	Based on faeces	Best estimate
2	6000	5000	6000	486	405	486
9	15000	19000	16000	240	320	270
10	2917	6215	3375	275	586	318
13	120	30	120	600	150	600
20	No data	15000	15000	No data	1220	1220
24	1950	12700	12700	214	1397	1397
25	6500	9300	6500	230	330	270
28	8667	7548	8108	71.9	62.6	67.3
30	3400	20000	20000	240	No data	240
32	0.0011	82.3	82.3	0.0000109	0.817	0.817
33	5300	3950	4600	430	320	375
38	1700	18000	9900	14	150	80
41	12000	18000	15000	300	450	380
42	5746	3755	5746	465	304	465
48	3210	13420	13420	143	140	140
49	69	57680	57680	9.7	8.075	8.075
GM	2777	11348	5863	171	320	324
GSD	4.86	2.12	5.64	3.53	2.38	2.39
AM	5184	14969	12139	266	449	451
ASD	4335	13593	13476	179	409	395
Median	4350	13060	9004	240	320	347
Minimum	0.0011	30	82.3	1.1E-05	0.817	0.817
Maximum	15000	57680	57680	600	1397	1397

Table F6.2.3: Results for Subject A based on the new ICRP models (outliers in shadow)

Participant ID	Total intake of ^{239}Pu (Bq)			Committed effective dose due to total intake (mSv)		
	Based on urine	Based on faeces	Best estimate	Based on urine	Based on faeces	Best estimate
4	36400	33000	36400	146	132	146
5	29000	6300	13000	240	52	110
7	48400	5230	48400	418.5	45.2	418.5
8	5300	18000	5300	44	150	44
14	53400	33000	49000	323	200	300
15	35000	30000	35000	300	93	300
17	46200	28400	46200	400	246	400
21	50000	30000	40000	No data	No data	600
27	72000	64000	69000	8600	7700	7600
29	60000	32000	46000	184	98	141
31	35000	52000	35000	290.5	No data	290.5
34	36900	30900	30900	319	267	267
37	970	1170	1100	31	37	35
39	475	6200	6200	17	224	224
44	29000	6300	6300	290	63	63
46	43958	28301	43958	272	175	272
47	47000	26000	36000	251	140	200
GM	42994	21115	27039	175	115	185
GSD	1.3	2.23	2.29	2.70	1.92	2.27
AM	44447	26852	34166	235	137	238
ASD	12137	16275	18094	126	77	152
Median	45079	29200	36200	272	136	246
Minimum	475	1170	1100	17	37	35
Maximum	72000	64000	69000	8600	7700	7600

Table F6.2.4: Results for Subject B (outliers in shadow)

Participant ID	Total intake of ^{239}Pu (Bq)			Committed effective dose due to total intake (mSv)		
	Based on urine	Based on faeces	Best estimate	Based on urine	Based on faeces	Best estimate
2	1500	1000	1250	122	81	101
4	16300	9400	16300	65	38	65
5	6000	1300	2800	50	11	23
7	3040	6130	3040	26.3	53	26.3
8	1500	3000	1500	12	25	12
9	3200	4000	3600	53	66	59
10	558	1273	712	51	120	67
13	30	7	30	170	40	170
14	20300	10000	15000	123	66	98
15	4000	14000	4000	35	43	35
17	5400	13600	13600	47	118	118
20	No data	4100	4100	No data	330	330
21	20000	10000	15000	No data	No data	200
24	632	7540	7540	69.5	829	829
25	980	4700	980	35	170	85
27	16000	17000	17000	1900	2000	2000
28	2459	1828	2144	20.4	15.2	17.8
29	23000	11000	17000	70	34	52
30	650	6000	6000	45		45
31	8000	8000	8000	66.4		66.4
32	0.0000767	30.6	30.6	0.000000761	0.304	0.304
33	1400	1600	1500	110	130	120
34	2820	9010	9010	24	78	78
37	120	415	400	3.8	15	13
38	300	4300	2300	2.5	36	19
39	300	6250	6250	10.8	226	226
41	2400	3800	3100	60	95	78
42	1395	805	1395	113	65	113
44	6500	4500	4500	65	45	45
46	4126	10210	10210	26	63	63
47	14600	7000	8000	88	42	48
48	210	4086	210	9.4	4.3	9.4
49	8	17003	17003	1.1	2.38	2.38
GM	2503	5065	4361	47	58	58
GSD	4.34	2.34	2.86	2.15	2.29	2.46
AM	5782	6748	6774	60	80	82
ASD	6971	4605	5719	40	73	72
Median	2820	6065	4300	52	63	64.8
Minimum	0.0000767	7	30.6	0.000000761	0.304	0.304
Maximum	23000	17003	17003	1900	2000	2000

Table F6.2.5: Results for Subject B based on the old ICRP models (outliers in shadow)

Participant ID	Total intake of ^{239}Pu (Bq)			Committed effective dose due to total intake (mSv)		
	Based on urine	Based on faeces	Best estimate	Based on urine	Based on faeces	Best estimate
2	1500	1000	1250	122	81	101
9	3200	4000	3600	53	66	59
10	558	1273	712	51	120	67
13	30	7	30	170	40	170
20	No data	4100	4100	No data	330	330
24	632	7540	7540	69.5	829	829
25	980	4700	980	35	170	85
28	2459	1828	2144	20.4	15.2	17.8
30	650	6000	6000	45		45
32	0.0000767	30.6	30.6	0.000000761	0.304	0.304
33	1400	1600	1500	110	130	120
38	300	4300	2300	2.5	36	19
41	2400	3800	3100	60	95	78
42	1395	805	1395	113	65	113
48	210	4086	210	9.4	4.3	9.4
49	8	17003	17003	1.1	2.38	2.38
GM	542	3201	1293	34	41	61
GSD	5.56	2.33	5.96	4.43	7.62	4.21
AM	1123	4431	3243	62	132	136
ASD	991	4121	4244	51	211	208
Median	815	4043	1822	52	66	78
Minimum	7.7 E-05	7	30	7.6 E-07	0.304	0.304
Maximum	3200	17003	17003	170	829	829

Table F6.2.5: Results for Subject B based on the new ICRP models (outliers in shadow)

Participant ID	Total intake of ^{239}Pu (Bq)			Committed effective dose due to total intake (mSv)		
	Based on urine	Based on faeces	Best estimate	Based on urine	Based on faeces	Best estimate
4	16300	9400	16300	65	38	65
5	6000	1300	2800	50	11	23
7	3040	6130	3040	26.3	53	26.3
8	1500	3000	1500	12	25	12
14	20300	10000	15000	123	66	98
15	4000	14000	4000	35	43	35
17	5400	13600	13600	47	118	118
21	20000	10000	15000	No data	No data	200
27	16000	17000	17000	1900	2000	2000
29	23000	11000	17000	70	34	52
31	8000	8000	8000	66.4		66.4
34	2820	9010	9010	24	78	78
37	120	415	400	3.8	15	13
39	300	6250	6250	10.8	226	226
44	6500	4500	4500	65	45	45
46	4126	10210	10210	26	63	63
47	14600	7000	8000	88	42	48
GM	7475	8512	7592	35	46	53
GSD	2.34	1.57	2.12	2.53	2.17	2.33
AM	10106	9273	9451	47	61	73
ASD	7406	3720	5524	33	55	62
Median	6500	9400	8505	47	44	58
Minimum	120	415	400	3.8	11	12
Maximum	23000	17000	17000	1900	2000	2000

Table F6.2.6: Model(s) applied

Participant ID	Respiratory tract	Systemic biokinetics	Urinary excretion	Faecal excretion	F1-factor	Tissue weighting factor	Dose coefficient
2	ICRP 30 (Y, 1 μm)	ICRP 54	Jones	ICRP 54 Durbin		ICRP 26	
4	ICRP 66 (S, 10 μm)	ICRP 67	Jones	Durbin	1 E-05	ICRP 60	4 E-06
5	ICRP 66 (S, 5 μm)	ICRP 67	ICRP 67	ICRP 30	1 E-05	ICRP 60	
7	ICRP 66 (S, 5 μm)	ICRP 54	Various	Durbin	1 E-05	ICRP 60	
8	ICRP 66 (S, 5 μm)	ICRP 48					ICRP 72
9	ICRP 30 (Y/S, 10 μm)	ICRP 54	ICRP 54	ICRP 54 Durbin			ICRP 72
10	No data						
13	ICRP 30 (Y, 10 μm)						
14	ICRP 66 (S, 10 μm)		Jones				6.056 E-06
15	ICRP 66 (S, 5/20μm (urine/faeces))		ICRP 54 Jones	ICRP 54 Durbin			
17	ICRP 66 (S, 5 μm)	ICRP 54	ICRP 30 Durbin	ICRP 30 Durbin	1 E-05		
20	ICRP 30 (Y, 10 μm)		Durbin	Durbin			
21	ICRP 66 (S, 5 μm)	ICRP 54					
24	ICRP 30 (W, 10 μm)	ICRP 30		ICRP 30			
25	ICRP 30 (Y, 5 μm)	ICRP 30 part 4	Jones	Jones		ICRP 26	
27	ICRP 66 (F, 10 μm)	ICRP 67	Jones				
28	ICRP 30 (Y, 5 μm)		ICRP 54	ICRP 54	1 E-05		ICRP 68
29	ICRP 66 (S, 20 μm)	ICRP 67	ICRP 67	ICRP 67	5 E-04	ICRP 60	IDSS
30	ICRP 30 (W, 10 μm)		ICRP 54	ICRP 54			
31	ICRP 66 (S, 5/20μm (urine/ faeces))	ICRP 67			1 E-05		ICRP 68 8.3 E-06

Table F6.2.6 (continued): Model(s) applied

Participant ID	Respiratory tract	Systemic biokinetics	Urinary excretion	Faecal excretion	F1-factor	Tissue weighting factor	Dose coefficient
32	ICRP 30 (5 μm)						
33	ICRP 30 (Y, 1 μm)	ICRP 30 part 4					ICRP 30 part 4
34	ICRP 66 (S, 5 μm)		ICRP 54	ICRP 54		ICRP 60	ICRP 68
37	ICRP 66 (M, 5 μm)	ICRP 68					3.2 E-05
38	ICRP 30 (Y, 10 μm)		ICRP 54	ICRP 54			ICRP 68
39	ICRP 66 (S, 5 μm)						
41	ICRP 30 (Y, 10 μm)		ICRP 54	ICRP 54			2.5 E-05
42	ICRP 30 (Y, 1 μm)		ICRP 54	ICRP 54			8.1 E-05 (1 μm AMAD)
44	ICRP 66 (S, 5 μm)	ICRP 68 ICRP 71					1 E-05
46	ICRP 66 (S, 10 μm)	ICRP 67					
47	ICRP 66 (S, 10 μm)	ICRP 67	ICRP 68				6.05 E-06
48	ICRP 30 (Y, 3 μm)	ICRP 30 ICRP 54	ICRP 30 ICRP 54	ICRP 30 ICRP 54	1 E-05		4.46E-05 Inh 1.36E-09 Ing
49	ICRP 30 (W, 10 μm)		ICRP 54	ICRP 54			ICRP 30

Table F6.2.7: Data handling

Participant ID	Data used for calculation		Handling of measurements below LLD
	Urine	Faeces	
2	all	all except first sample of sub.A and first two samples of sub.B	n.s.
4	all except first urine of both subjects	all	Set to 1 mBq/d
5	all	all	n.s.
7	all	all except first faeces of both subjects	Set to 1 mBq/d
8	all	Selected data	n.s.
9	all	all	n.s.
10	n.s	n.s.	n.s.
13	all	all	n.s.
14	all by the end of 1988	all	ignored
15	all	all	n.s.
17	all	all	< 1 mBq/d was set to = 1 mBq/d
20	all	all except first sample of sub.A	n.s.
21	all	all	n.s.
24	all	all	n.s.
25	all	all	n.s.
27	all by the end of June 1983	all by the end of June 1983 except of 6.6.83	n.s.
28	all except first day	all except first day	n.s.
29	all except first sample of sub.B	all	n.s.
30	all	all	n.s.
31	all	all	0 ± LLD
32	All (?)	All (?)	n.s.
33	all	all except first samples of both subjects	n.s.
34	all	all	0 ± LLD
37	n.s.	n.s.	n.s.
38	all for t < 30d	all	n.s.
39	all	all	Ignored
41	all significant	all significant	n.s.
42	all	all except 1st sample	< 1 mBq/d set to = 1 mBq/d
44	n.s.	n.s.	n.s.
46	all	all	n.s.
47	all	all	n.s.
48	all	all	set 0
49	n.s.	n.s.	n.s.

Table F6.2.8: Additional information

Participant ID	
2	In spite of the case description the best fit considering both faecal and urinary data was obtained assuming 1 µm AMAD particles. Possible higher AMAD component to explain early faecal data. But not dosemetricaly significant
4	Influence of activity removal by nose swab and bronchial slime was not considered. Increase of late urinary excretion could not be explained.
5	The faecal to urine data indicated that the inhaled particles were relatively insoluble. Type S was assumed because of better fitting to the data as compared to type M. Log errors were assumed when assessing intake.
7	An attempt to fit the data including the first faecal results was made, but was ignored because no fit could be made to known excretion patterns. Therefore intake estimates and doses are based on the bioassay data excluding the first day faecal excretion.
8	
9	Nose swab and bronchial slime data have been used to specify inhaled and ingested fractions (80 % inhalation and 20 % ingestion).
10	
13	
14	
15	
17	Intake has been calculated using the Weighted Least-Square Fit procedure of Skrable. The particle size was selected as best fitting value. The best estimates were selected according to minimal standard deviation (urine based values for subject A and faeces based values for subject B.
20	
21	Total intake by faeces measurements is based on the sum of measured and interpolated faecal excretion data during day 1-3 after inhalation.
24	
25	Particle size: AMAD was varied to obtain better agreement between intake based on urine and faeces, respectively. This proved unsatisfactory, particularly for Subj. B. The default value of 5 µm AMAD was therefore used.
27	Absorption type F was used because of better consistency of the results based on urine and faeces, respectively, as compared to absorption type M. An alternative approach based on ICRP30, ICRP48 and ICRP54 (Class W and 10 um AMAD) gives similar results (be
28	Because of the larger dimensions of the inhaled particles (3-40 µm AMAD), in the first day a larger fraction of the inhaled particles is coming back from the TB to the NP compartment, and the being swallowed. This affects the first day excretion and thus
29	Intake has been obtained as best fit of the computer code IMIE 3.0 (figures)
30	It was supposed that 50 % of the intake was due to inhalation and 50 % due to ingestion.
31	Best fit to data has been found using 5 µm AMAD for the urine data and 20 µm AMAD for the faecal data, respectively. The intake values refer to the respective particle sizes. Since only the dose coefficient for 5 µm AMAD was available, only the dose based on urine data was calculated.
32	The best estimate is obtained as arithmetic mean of the results based on urine, faecal and lung data, respectively; for this purpose the faecal excretion value of d 8923 is set equal to the LLD
33	Although experimental evidence would suggest large particles of class W material a better fit to the data was found using 1 µm AMAD of inhalation class Y. This gave a good fit to the time variation in urine excretion and to match between intakes based on

Table F6.2.8 (continued): Additional information

Participant ID	
34	
37	
38	Urine data for t > 30 d were neglected because of increasing discrepancy to the ICRP54 function. Class Y was selected because of consistency of urine and faeces data. Best estimates were calculated as average of urine and faeces based results. The effective
39	Faecal selected for best estimate.
41	The CINDY code revealed much better consistency of urine and faeces results than LUDEP.
42	For dose calculation the effective dose coefficient for 1 µm AMAD has been applied.
44	The fitting procedure is using logarithmic least-square techniques.
46	For subject B faecal data gave a better fit, and thus for subject B the best estimate is based on faeces whereas for subject A the best estimate is based on urine. An alternative calculation using GENMOD V 3.02 with ICRP30 models resulted in the following b
47	Deconvolution approach based on ICRP 78 (DECODIX)
48	For subject A the intake based on faeces is splitted into 10300 Bq (77 %) due to ingestion and 3120 Bq (23 %) due to inhalation, the latter being consistent with the intake based on urine, which has been calculated assuming 100 % inhalation. Similar splitt was made for subject B: 3990 Bq Ingest. (98 %), 96 Bq Inhal. (2 %).
49	Intake for subject A from nose swab: 30.6 kBq (ICRP66)

F6.3 Example I

Assessed by: *F. Del Dottore, G. Sarti, Health and Medical Physics Dept., Bufalini Hospital of Cesena, Italy*

Introduction:

Two occupational workers received a single acute intake of ^{239}Pu via inhalation of radioactive aerosol, which originated from an explosion of a glove-box containing an U/Pu hydroxide gel in water compound. For both the subjects, repeated activity measurements of daily urinary and faecal excretion rate were performed, starting the first day after the accident for the following eight years. Besides, on one of the two workers measurements were performed on nose swab and bronkial slime. The results of the collected samples were provided. As no errors were reported, they were assumed to be not significative compared to the results.

We were requested to calculate the total intake of ^{239}Pu and the committed effective dose due to the total intake of ^{239}Pu for both the subjects. The values had to be obtained separately from urine and feces data, furthermore the best estimate had to be given.

Models and computer tools used for the assessment:

The case was analized as follows:

Models applied:	ICRP Publication 30
	ICRP Publication 54
Type of models:	Respiratory system model
	Inhalation of radioactive aerosol
	Urinary, faecal excretion models
Model parameters:	Retention Class Y
	AMAD = 1μm
Data used for calculation:	Urine activity measurements
	Feces activity measurements

The fitting procedures between the measurements data and the model functions were performed using a commercial program for numeric computation and graphical representation, the intake and dose calculations were performed using an Excel spreadsheet.

Assessment procedures:

The inhaled substance was classified as Class Y aerosol on the basis of the following considerations:

- The urinary excretion measurements for both the subjects show detectable levels of activity concentration over a time scale of years and, excluding the first two weeks after the intake, all the values belong to the same order of magnitude. The very slow decreasing in the activity concentration allowed us to classify the inhaled substance as Class Y aerosol on the basis of ICRP 30, where materials are classified according to their clearance half-time from the pulmonary region.

- Further evidence was provided by comparing the experimental urinary excretion data with the model dismission curves: the measurements data are clearly better fitted by the dismission curve for acute intake by inhalation, ^{239}Pu Class Y given in ICRP 54.

- The interpretation of faecal excretion data still again confirmed the long-term accumulation of Plutonium in the body, since detectable levels of activity concentration still appear over a time scale of years. However, the analysis of faecal samples involves uncertainty owing to fluctuations in faecal daily excretion rate; therefore, it gets difficult to identify the standard curve that matches the experimental data.

- The information given on the chemical reaction wich produced the aerosol was considered to be insufficient to definitely apply the classification given in ICRP 30, 54, according wich it is possible to define a substance as Class Y or W depending on its chemical form.

The choice of the particle size value of AMAD = 1 μm arised from the following considerations:

- The experimental urinary excretion curves were correlated to the standard excretion curves in ICRP 54. It was not ignored the fact that the measured activity values tend to rise 2000 days after the intake.

- Being the model curves for AMAD = 1 μm and AMAD = 0.2 μm equally good to fit the measurements data, the default value of AMAD = 1 μm was assumed.

- Additional information about the nose swab and bronchial slime measurements does not provide a good basis to determine the fractions of inhaled material initially deposited in the N-P, T-B and P regions of the respiratory system, in order to determine the particle size as described in ICRP 30.

Intake assessment:

Using the predictive factors from ICRP 54, daily urinary and faecal excretion curves, acute intake by inhalation model (Class Y aerosol, AMAD = 1 μm), the intake was obtained from the arithmetic mean all over the whole period of monitoring.

It must be noted that, for both the subjects, the fecal samples which were collected the first day after the accident show a much higher activity concentration than that of the other days. Supposing that the first day samples were contaminated with unmetabolized material, they were rejected for intake assessment.

Dose assessment:

According to ICRP 54, it was applied the committed effective dose equivalent factor 8.1×10^{-5} $SvBq^{-1}$.

Results:

	Total intake of Pu-239 (Bq)			Committed effective dose due to total intake of Pu-239 (mSV)		
	based on urine	based on feces	best estimate	based on urine	based on feces	best estimate
Subject A	5746	3755	5746	465	304	465
Subject B	1395	805	1395	113	65	113

There is a good agreement between the results based on urine and feces. For the reasons previously considered, the results based on urinary measurements were regarded as the most reliable.

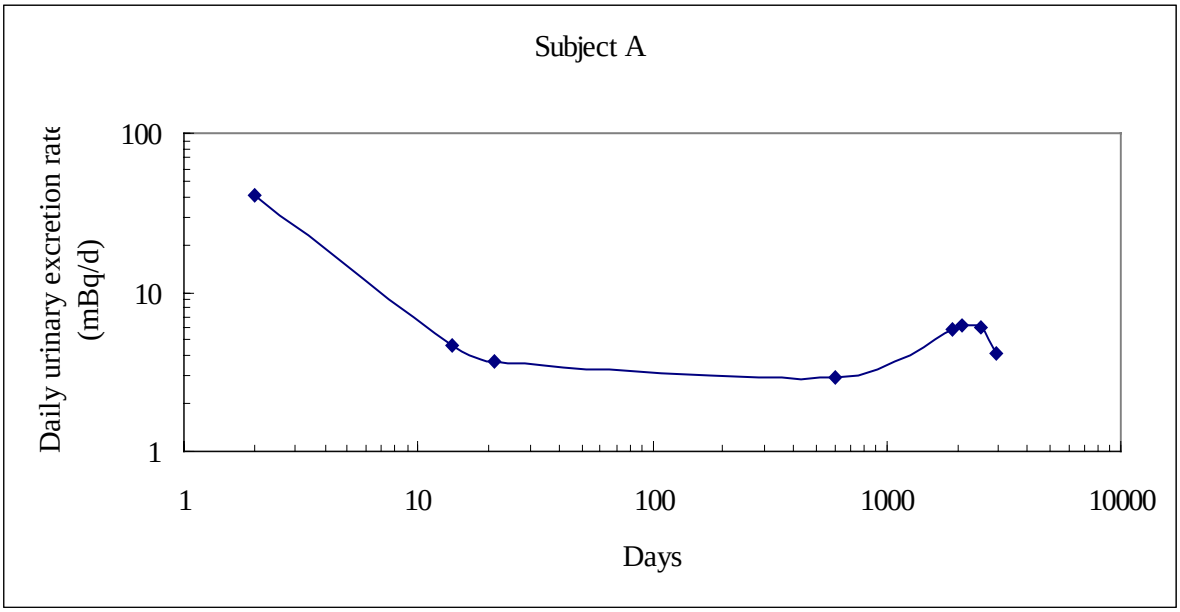

Fig. F6.3.1: Daily urinary excretion rate of Subject A

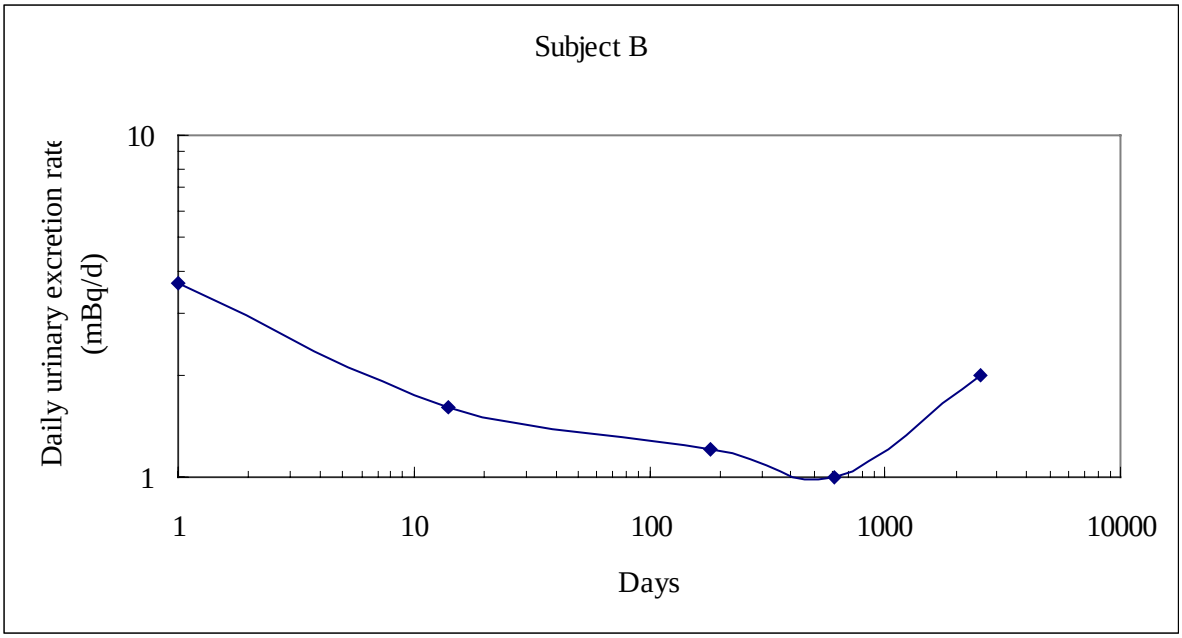

Fig. F6.3.2: Daily urinary excretion rate of Subject B

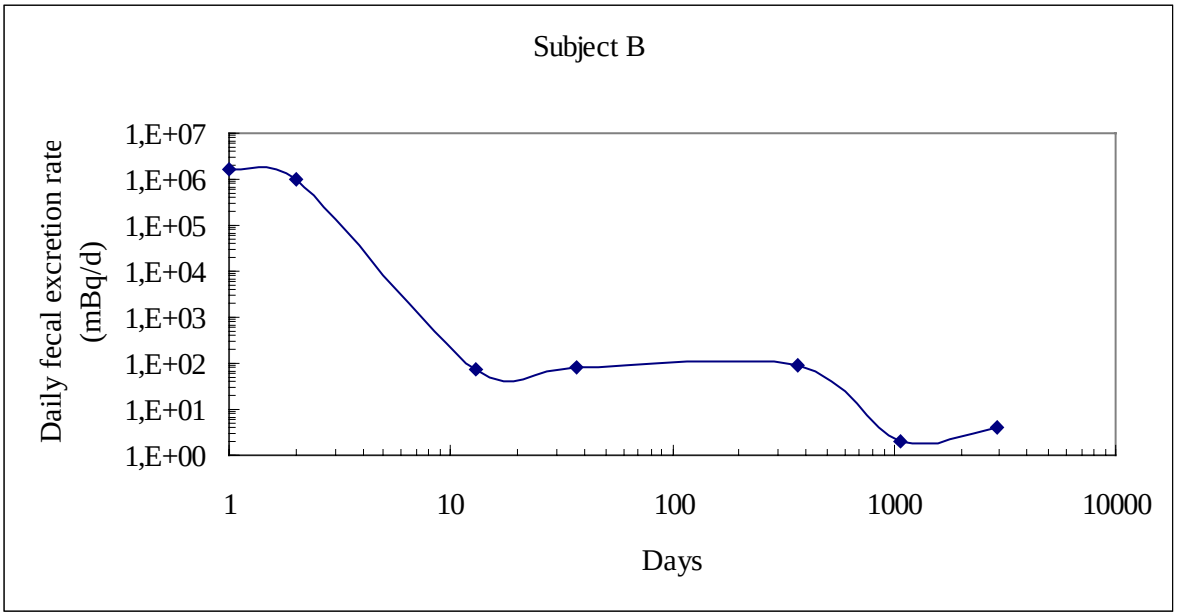

Fig. F6.3.3: Daily fecal excretion rate of Subject A

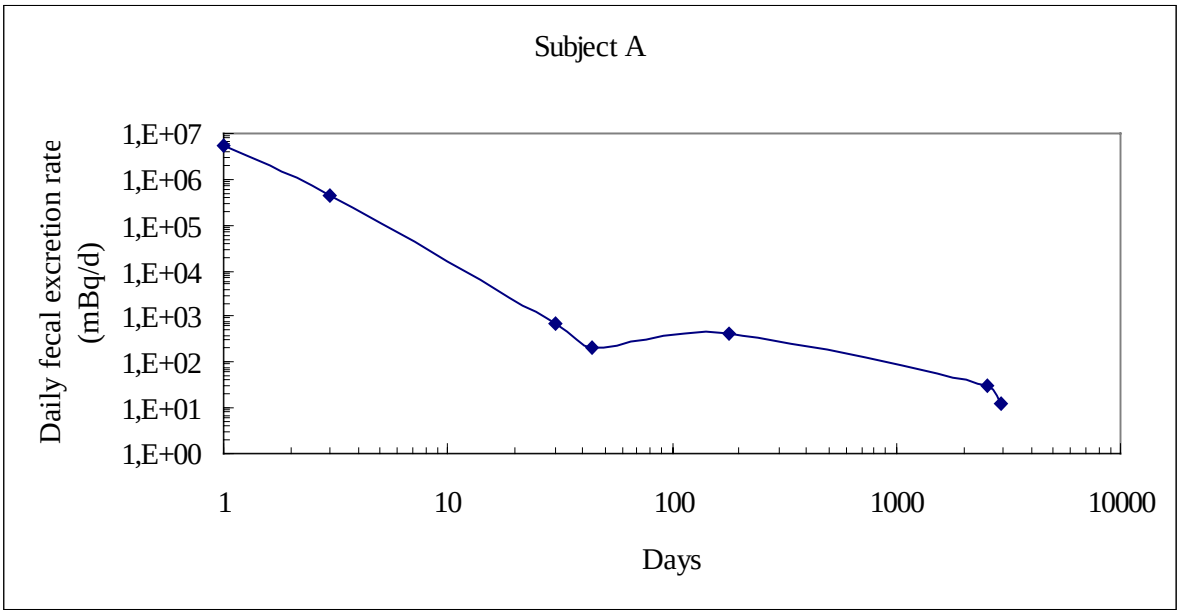

Fig. F6.3.4: Daily fecal excretion rate of Subject B

F6.4 Example I

Assessed by: J-P. Culot, AV NUCLEAR, Bruxelles, Belgium

Introduction

This case is certainly one of the best-documented case of a single intake of transuranium elements. There is a set of excretion and organ burden data from the first day after intake over a time period of almost ten years available.

The complete set of data was chosen as « Case 8 » in the intercomparison organised by the IAEA [IAEA99]

As a participant to this work, I provided results obtained with the ICRP 30/54 biokinetic model, assuming an AMAD of 1 µm, which seems to be inconsistent with the given information on the distribution of diameters for the inhaled particles (3 to 40 µm). It will be reminded that the 1 µm is the standard option for the old ICRP models and that we did not know the effect of the nose swab and of the bronchial slime removal on the amount of large particles remaining in the pulmonary region.

The analysis of the lung retention of Am-241 has shown that it was necessary to modify the ICRP 30 lung model by increasing the retention time in the pulmonary region: 2000 days for compartment e, g and h.

Another assumption was to accept the same biokinetic for all the isotopes of plutonium and to use the sum of the excreted activities respectively for the urine and the faeces. Using the RBD 4.1 software package [ECK93], it was possible to obtain a satisfactory least squares fit for all the data and also to explain the observed increase in the late urinary excretion due to small particles deeply imbedded in the pulmonary region. Bigger particle were removed by the nose swab and the bronchial slime removal.

Eurados intercomparison

In this intercomparison we use the most biokinetic models defined by the ICRP: ICRP 66 for the lungs and ICRP 67 for the plutonium metabolism.

Computer code applied

A first analysis of the data was made using LUDEP (V. 2.05) which include the new lung model (ICRP 66) but still use the old biokinetic model derived from ICRP 30.

A more accurate analysis with the ICRP 67 biokinetic model was made with an «in house» computer code which consists of several parts. The central part is a computer-efficient program written by R.W. Leggett and K.F. Eckerman [LEG93] for implementing complex compartmental models, with attention focused primarily on biokinetic models involving time dependent transfer rate and recycling. The input module is a data processing unit converting standard information (lung model parameters, biokinetic model parameters) to formatted data,

which are read in by the main program. The third part is a result processing unit that allows the reading of specifics results (amount or number of disintegration in a specific compartment), the making of graphs and the computation of excretion curve by differentiation of the retention in the urine and faeces compartments. The fourth part computes the dose factors and the effective doses assuming ICRP 26 or ICRP 60 weighting factors and using SEE factors calculated with the SEECAL program (V. 2.0, K.F. Eckerman, ORNL).

The program has been validated by comparisons with excretion, retention and dose values given in the ICRP 68, 71 and 78 for class S and 5 µm.

Delay (days)	Urinary excretion		Faecal excretion	
	ICRP	Calculated	ICRP	Calculated
1	$2.3\ 10^{-6}$	$2.24\ 10^{-6}$	$1.1\ 10^{-1}$	$1.15\ 10^{-1}$
10	$2.3\ 10^{-7}$	$2.32\ 10^{-7}$	$6.5\ 10^{-4}$	$6.62\ 10^{-4}$
180	$1.6\ 10^{-7}$	$1.66\ 10^{-7}$	$3.7\ 10^{-5}$	$3.91\ 10^{-5}$

For an acute inhalation, with a polydisperse aerosol (AMAD = 10 µm, density = 3, σg = 2.5, sf = 1.5), we note a significant difference for the calculated dose factor using LUDEP or our «in house» program. The use of the new model results in a decrease of about 30 % for the dose factor.

Model	Dose factor (µSv/Bq)
ICRP 66 + ICRP 30	6.1
ICRP 66 + ICRP 67	4.0

Choice of the parameters for the biokinetic models

A first analysis made with LUDEP shows that the urinary and faecal excretions could be described assuming a class S contaminant with an AMAD close to the default value (5 µm).

However, looking at the distribution of the diameter of the particles, it will be better to use a value of 10 µm because the distribution of diameters covers the observed range (3 to 40 µm).

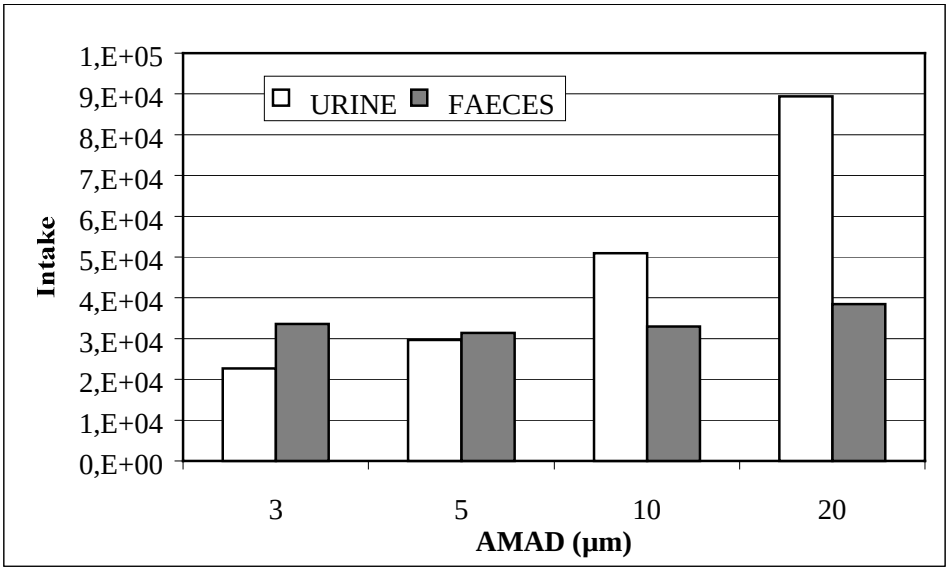

Fig. F6.4.1: Case A. LUDEP screening

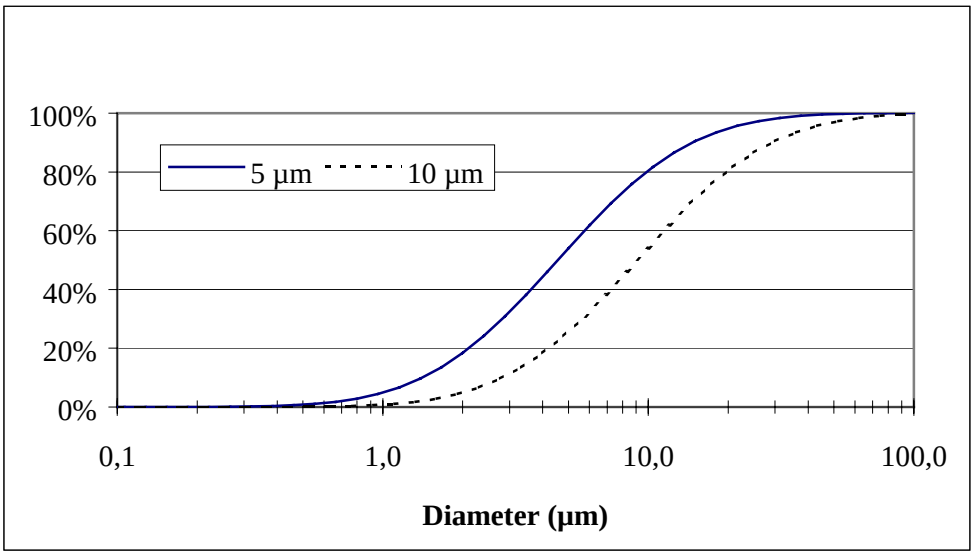

Fig. F6.4.2: Distribution of inhaled particles

Finally our model could be described in the following way:

Acute inhalation

- Class S
- AMAD = 10 µm, σ_g = 2.5
- Density = 3
- Occupational standard worker, mean ventilation rate = 1.2 m³/h
- $f_1 = 10^{-5}$

Calculation of the intakes

The data used for the calculation are:
- Urinary excretion: excluding the first value
- Faecal excretion: including all the data

The least squares fit was made with the module included in LUDEP, using the option «uniform absolute error».

Urinary excretion			
Case	Intake (kBq)	Uncertainty (kBq)	95% range (kBq)
A	36,4	2,0	32,5 - 40,4
B	16,3	3,2	9,9 - 22,6

Faecal excretion			
Case	Intake (kBq)	Uncertainty (kBq)	95% range (kBq)
A	33,0	8,0	17,4 - 48,7
B	9,4	1,7	6,0 - 12,8

Calculation of the committed effective dose

Using the dose factor of 4.0 µSv/Bq, we compute the following doses.

Case	Urine		Faeces	
	Dose (mSv)	Uncertainty (mSv)	Dose (mSv)	Uncertainty (mSv)
A	146	8	132	32
B	65	13	38	7

Summary

The results derived from urinary and faecal excretion are combined (Weighted mean).

	Total intake of ^{239}Pu [kBq]			Committed effective dose due to total intake of ^{239}Pu [mSv]		
	Based on urine	Based on faeces	Weighted mean	Based on urine	Based on faeces	Weighted mean
Subject A	36.4	33.0	36 ± 2	146	132	145 ± 8
Subject B	16.3	9.4	11 ± 2	65	38	44 ± 6

Urinary excretion

We obtain quite a good fit for the 2 cases but we are not able to modify the model for obtaining a better fit for the late urinary excretion (Fig. F6.4.3).

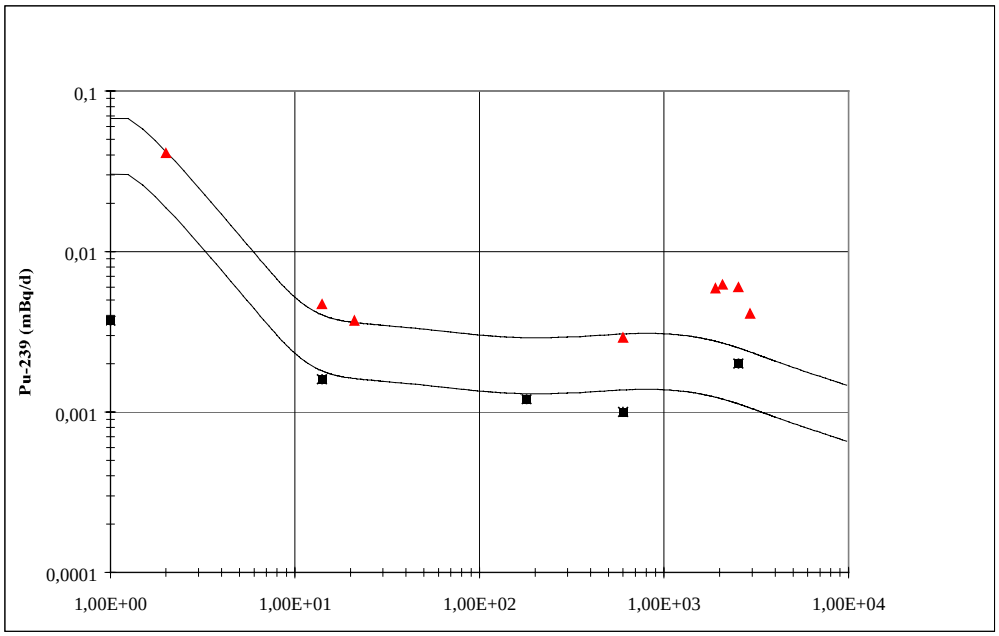

Fig. F6.4.3: Comparison of measurement and model calculation of the urinary excretion

Faecal excretion

For the 2 cases, the fit seems to be reasonable (Fig. F6.4.4).

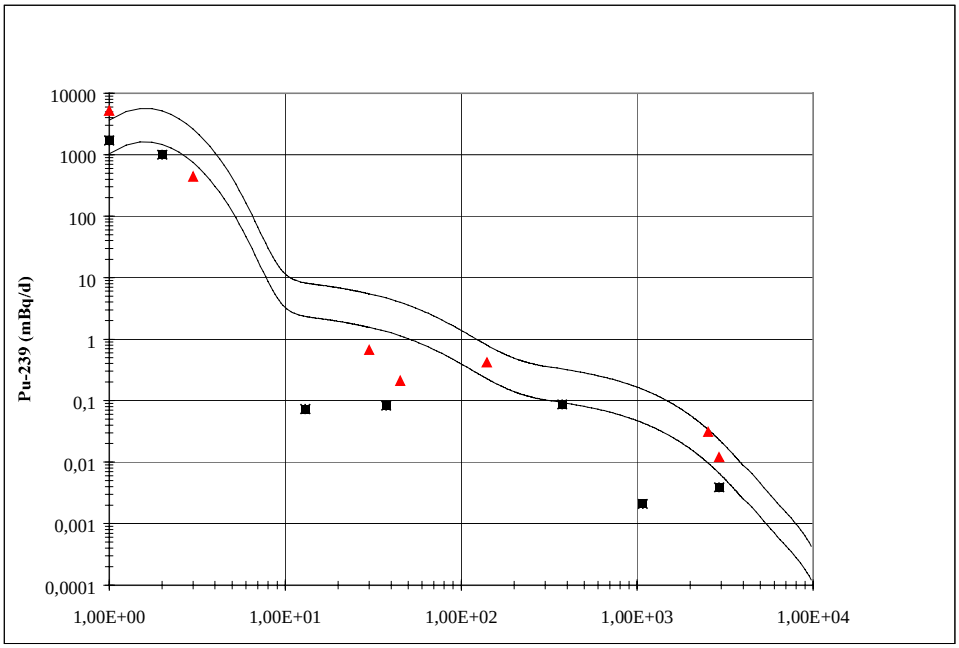

Fig. F6.4.4: Comparison of measurement and model calculation of the fecal excretion

F7 Reconstruction of an exposure to Pu

F7.1 Case description

Main characteristics

- Radiation worker
- Real case with exposure long time before investigation
- Intake path unknown
- Urine, feces and organ measurement
- Retrospective evaluation with most values being below the detection limit

F7.1.1. The event

F7.1.1.1 *Description of the working area*
Radiochemical laboratory in a nuclear research centre

F7.1.1.2 *Characteristics of work*
In the laboratory different kind of research work has been performed most of which being related to the development of nuclear fuel. During this work significant amounts of Plutonium have been handled inside glove boxes.

F7.1.1.3 *Reasons for monitoring; initiating event*
In 1990 routine incorporation monitoring resulted in significant excretion rates of Plutonium in urine and feces for a person working for more than 25 years in the institute. Room air monitoring, however, gave not any indication of a Plutonium exposure in the time before.

F7.1.1.4 *Actions taken*
The working history of the person has been studied in detail. The files 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 (5 pCi). Thus, no additional investigations have been performed at this time. After having found the positive results in 1990, however, the case had to be evaluated once more, taking into account all information availabele. 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.
Between 1965 and 1989 routine incorporation monitoring resulted in 4 positive urine samples out of a total of 56 samples. The highest value was 40.7 mBq (11 pCi)

F7.1.2. Additional information

F7.1.2.1 *Air monitoring*
There were stationary room air samplers, but there are no data available.

F7.1.2.2 *Chemical form*
Freshly separated Plutonium (separation process unknown)

F7.1.2.3 *Physical characteristics, particle size*
The alpha activity composition of the Plutonium was 76 % Pu-239 and 24 % Pu-240. The beta activity of Pu-241 was a factor of 9.7 higher than the total alpha activity of Pu-239 + Pu-240. Further information is not available.

F7.1.2.4 *Nose swab, bronchial slime or similar*

none

F7.1.2.5 *Non removable skin contamination*

No data

F7.1.2.6 *Wound site activity*

No data

F7.1.2.7 *Any intervention used (blocking, chelating, etc.)*

None

F7.1.3. Personal Data

F7.1.3.1 *Sex*

Male

F7.1.3.2 *Age (at the year of the incident)*

29 years

F7.1.3.3 *Weight*

105 kg

F7.1.4. Body monitoring data

F7.1.4.1 *Whole body activity measurements*

none

F7.1.4.2 *Organ activity measurement*

Days after the assumed intake	Am-241 activity [Bq]		
	Lungs and lymphn.	Liver	Skeleton
6952	20 ± 5	No data	No data
7901	18 ± 5	No data	No data
8917	24 ± 5	< 6	19 ± 10

F7.1.5. Excretion monitoring data

F7.1.5.1 *Urine activity measurement*

Urine activity measurements have been performed routineously from day 7 until day 9287 after the assumed intake. The values given in the table below refer to the excretion of ^{239}Pu and ^{240}Pu. The lower detection (LLD) was 18.5 mBq/d (5 pCi/d) for the first measurement. Due to the improvement of measuring techniques the LLD was reduced step by step to 7.4 mBq/d (2 pCi/d), 3.7 mBq/d (1 pCi/d) and 1.5 mBq/d. The LLD value of 1.5 mBq/d refer to the worst detector out of a total of 15 detectors of the laboratory. Most of the other detectors have significant lower LLD's and so values below 1.5 mBq/d derived after day 9227 might be significant. These values are given in brackets in the table below.

Days after the assumed intake	Excretion rate [mBq/d]	Days after the assumed intake	Excretion rate [mBq/d]	Days after the assumed intake	Excretion rate [mBq/d]
7	< 18.5	2337	< 3.7	6645	< 1.5
226	< 7.4	2583	< 3.7	6950	1.7
363	< 7.4	2676	< 3.7	6987	< 1.5

(continued)

Days after the assumed intake	Excretion rate [mBq/d]	Days after the assumed intake	Excretion rate [mBq/d]	Days after the assumed intake	Excretion rate [mBq/d]
454	< 7.4	2871	< 3.7	7290	< 1.5
545	7.4	3115	< 3.7	7291	< 1.5
657	< 3.7	3241	< 3.7	7292	< 1.5
743	< 3.7	3332	< 3.7	7419	< 1.5
834	14.8	3446	< 3.7	8392	< 1.5
876	< 3.7	3621	< 3.7	8835	< 1.5
930	< 3.7	3634	< 3.7	8921	< 1.5
1035	< 3.7	3753	< 3.7	8922	< 1.5
1108	40.7	3884	< 3.7	8923	< 1.5
1127	< 3.7	4031	< 3.7	9185	2.3
1217	< 3.7	4220	< 3.7	9227	(0.2)
1339	< 3.7	4550	< 3.7	9228	1.8
1434	< 3.7	4724	< 3.7	9229	(0.7)
1570	< 3.7	4864	< 3.7	9254	(1.1)
1728	< 3.7	4941	< 3.7	9255	2.3
1834	< 3.7	5125	< 1.5	9256	(1.1)
1961	< 3.7	5481	< 1.5	9285	1.7
2079	< 3.7	5942	< 1.5	9286	2.9
2191	< 3.7	6385	< 1.5	9287	1.6

F7.1.5.2 *Feces activity measurement*

Feces activity measurements have been performed routineously from day 7290 until day 9287 after the assumed intake. The values given in the table below refer to the excretion of ^{239}Pu and ^{240}Pu (LLD 1.5 mBq/d).

Days after the assumed intake	Excretion rate [mBq/d]
7290	4
7291	5.2
7292	7.1
7301	9.6
7302	9.5
7303	8.2
8921	2.3
8922	2.5
8923	< 1.5
9285	1.9
9286	2.6
9287	2.2

A7.1.6. Other comments relevant for intake and dose estimation

A7.1.7 Results

	Total intake of ^{239}Pu + ^{240}Pu [Bq]	Committed effective dose due to total intakeof ^{239}Pu + ^{240}Pu [mSv]
Based on urine		
Based on feces		
Based on ^{241}Am organ activity		
Best estimate		

Additional comments

F7.1.7.1 Computer code(s) applied
F7.1.7.2 Intake assumptions (path of intake)
F7.1.7.3 Model(s) applied
- F7.1.7.3.1 Standard ICRP models
  - F7.1.7.3.1.1 Type of models
  - F7.1.7.3.1.2 Model parameters (inhalation class or clearance type, AMAD etc.)
- F7.1.7.3.2 Other models
  - F7.1.7.3.2.1 Reason for applying other models
  - F7.1.7.3.2.2 Type of models
  - F7.1.7.3.2.3 Characteristical parameters

F7.1.7.4 Data handling
- F7.1.7.4.1 Data used for calculation (all data or selected data; please comment especially on the handling of the urine excretion value of day 1108 and also on the handling of the ^{241}Am organ activity values.)
- F7.1.7.4.2 Methods for handling of measurements below detection limit

F7.1.7.5 Additional information

F7.2 Answers of the participants

Table F7.2.1: Results (outliers in shadow)

Participant ID	Total intake of Pu-239 and Pu-240 (Bq)				Committed effective dose due to total intake of Pu-239 and Pu-240 (mSv)			
	Based on urine	Based on feces	Based on Am-241 organ activity	Best estimate	Based on urine	Based on feces	Based on Am-241 organ activity	Best estimate
2	2000	1300	1700	2000	509	331	433	509
4	42000	42000	60000	42000	350	350	500	350
5	25400	38600	No data	32000	213	324	No data	268
6	2800	25000	2720	2800	67.5	216.2	23.5	67.5
7	22000	35800	42800	32400	167.5	309.8	370.3	280.3
8	2500	5000	12000	2500	40	80	190	40
9	39000	48000	15000	39000	780	960	300	780
13	103000	6800	No data	103000	600	3.3	No data	600
14	4000	5000	No data	4600	167	210	No data	190
15	29000	29000	75000	29000	254	251	650	254
17	63500	38400	40000	47300	549	332	346	409
20	6200	50000	70100	50000	220	1800	2000	1800
25	3450	No data	No data	3450	120	No data	No data	120
27	43000	44000	160000	80000	220	225	820	410
29	7900	7800	10000	8000	126	125	160	128
30	2700	6800	2240	2240	240	605	200	200
31	13000	30000	2580	2580	108	250	21	21
32	0.000789	0.0011	5.48	No data	1.08E-05	0.0137	1.75E-05	0.0137
33	2735	20587	1544	2140	222	1668	125	173
34	13700	39000	29000	39000	114	324	241	324
38	11000	24000	25000	20000	165	360	375	300
39	25600	20600	12663	19600	212	171	105	163
41	3000	8000	No data	6000	240	650	No data	500
42	2000	10000	2000	2000	280	1400	280	280
44	30000	40000	80000	80000	300	400	800	800
46	312	219	302	300	291	204	283	280
47	35000	27700	No data	31000	525	420	No data	475
48	8580	17700	7360	17700	712	1470	611	1470
49	7850	10850	No data	10850	699	966	No data	966
GM	10900	19900	13900	13200	257	397	352	347
GSD	3.3	2.16	4.44	3.8	1.9	2.25	2.06	2.16
AM	20400	25200	32600	26300	313	554	463	465
ASD	23300	14900	40100	27400	205	501	429	412
Minimum	0.000789	0.0011	5.48	300	1.08E-05	0.0137	1.75E-05	0.0137
Maximum	103000	50000	160000	103000	780	1800	2000	1800

Table F7.2.2: Results based on the old ICRP models (outliers in shadow)

Participant ID	Total intake of Pu-239 and Pu-240 (Bq)				Committed effective dose due to total intake of Pu-239 and Pu-240 (mSv)			
	Based on urine	Based on feces	Based on Am-241 organ activity	Best estimate	Based on urine	Based on feces	Based on Am-241 organ activity	Best estimate
2	2000	1300	1700	2000	509	331	433	509
9	39000	48000	15000	39000	780	960	300	780
13	103000	6800	No data	103000	600	3.3	No data	600
20	6200	50000	70100	50000	220	1800	2000	1800
25	3450	No data	No data	3450	120	No data	No data	120
30	2700	6800	2240	2240	240	605	200	200
33	2735	20587	1544	2140	222	1668	125	173
38	11000	24000	25000	20000	165	360	375	300
41	3000	8000	No data	6000	240	650	No data	500
42	2000	10000	2000	2000	280	1400	280	280
47	35000	27700	No data	31000	525	420	No data	475
48	8580	17700	7360	17700	712	1470	611	1470
49	7850	10850	No data	10850	699	966	No data	966
GM	7394	13289	6232	9960	345	820	378	467
GSD	3.54	2.75	4.23	4.01	1.87	1.87	2.29	2.26
AM	17424	19311	15618	22260	409	966	541	629
ASD	28499	15912	23547	28934	235	541	608	512
Minimum	2000	1300	1544	2000	120	331	125	120
Maximum	103000	50000	70100	103000	780	1800	2000	1800

Table F7.2.3: Results (outliers in shadow)

Participant ID	Total intake of Pu-239 and Pu-240 (Bq)				Committed effective dose due to total intake of Pu-239 and Pu-240 (mSv)			
	Based on urine	Based on feces	Based on Am-241 organ activity	Best estimate	Based on urine	Based on feces	Based on Am-241 organ activity	Best estimate
4	42000	42000	60000	42000	350	350	500	350
5	25400	38600	No data	32000	213	324	No data	268
6	2800	25000	2720	2800	67.5	216.2	23.5	67.5
7	22000	35800	42800	32400	167.5	309.8	370.3	280.3
8	2500	5000	12000	2500	40	80	190	40
14	4000	5000	No data	4600	167	210	No data	190
15	29000	29000	75000	29000	254	251	650	254
17	63500	38400	40000	47300	549	332	346	409
27	43000	44000	160000	80000	220	225	820	410
29	7900	7800	10000	8000	126	125	160	128
31	13000	30000	2580	2580	108	250	21	21
34	13700	39000	29000	39000	114	324	241	324
39	25600	20600	12663	19600	212	171	105	163
44	30000	40000	80000	80000	300	400	800	800
GM	15719	23235	23642	17174	170	236	216	187
GSD	2.83	2.20	3.75	3.59	1.97	1.56	3.46	2.70
AM	23171	28586	43897	30127	206	255	352	265
ASD	17766	13946	45520	26341	131	91	284	201
Minimum	2500	5000	2580	2500	40	80	21	21
Maximum	63500	44000	160000	80000	549	400	820	800

Table F7.2.4: Model(s) applied

Participant ID	Respiratory tract	Systemic biokinetics	Urinary excretion	Fecal excretion	F1-factor	Tissue weighting factor	Dose coefficient
2	ICRP 30 (Y, 1 μm)	ICRP 48	Jones	Durbin		ICRP 26	
4	ICRP 66 (S, 5 μm)	ICRP 67	Jones	Durbin	1 E-05	ICRP60	8.3 E-06
5	ICRP 66 (S, 5 μm)	ICRP 67	ICRP 67	ICRP 67	1 E-05	ICRP 60	8.385 E-06 (LUDEP)
6	ICRP66 (S, 5 μm)	ICRP 30	Jones	Durbin	1 E-05	ICRP 60	
7	ICRP 66 (S, 5 μm)	ICRP 48/54	Jones/Tancock & Taylor	Durbin	1 E-05	ICRP 60	
8	ICRP66 (S, 1 μm)	ICRP 48					ICRP 72
9	ICRP 30 (Y, 5 μm)	ICRP 30	ICRP 54	Durbin			
13	ICRP 30 (Y, 10 μm)	ICRP 30	ICRP 30/54	ICRP 30/54			ICRP 54

Table F7.2.4 (continued): Model(s) applied

Participant ID	Respiratory tract	Systemic biokinetics	Urinary excretion	Fecal excretion	F1-factor	Tissue weighting factor	Dose coefficient
14	ICRP 66 (S, 0,1 µm)		Jones				4.162 E-05 (LUDEP)
15	ICRP 66 (S, 5 µm)		Jones	Durbin			
17	ICRP 66 (Pu:S, 5 µm) (Am:M,5µm)	ICRP 30	ICRP 54	ICRP 54	Pu: 1 E-05 Am: 1 E-03		8.652 E-06 (LUDEP)
20	ICRP 30 (Y, 5 µm)		Durbin	Durbin			
25	ICRP 30 (Y, 5 µm)	ICRP 30 part 4	Jones			ICRP 26	
27	ICRP 66 (S, 10 µm)	ICRP 67					
29	ICRP 66 (S, 1 µm)	ICRP 67	ICRP 67	ICRP 67	5 E-04	ICRP 60	ICRP 67
30	ICRP 30 (Y, 1 µm)	ICRP 30	Jones				
31	ICRP 66 (S, 5 µm)	ICRP 67			ICRP 71 1 E-05		ICRP 68
32						ICRP 26/60	
33	ICRP 30 (Y, 1 µm)		Jones				ICRP 54
34	ICRP 66 (F, 5 µm)	ICRP 30	Jones	ICRP 54		ICRP 60	
38	ICRP 30 (Y, 1 µm)	ICRP 30	ICRP 54	ICRP 54			ICRP 68
39	ICRP 66 (S, 5 µm)		Jones	Durbin			
41	ICRP 30 (Y, 1 µm)		ICRP 54	ICRP 54			
42	ICRP 30 (Y, 0,2 µm)		ICRP 54	ICRP 54			
44	ICRP 66 (S, 5 µm)				ICRP 71		ICRP 68
46		ICRP 30	ICRP 30	ICRP 30			ICRP 30
47	ICRP 30 (Y, 1 µm)	ICRP 30	ICRP 54	ICRP 54			
48	ICRP 30 (Y, 1 µm)		ICRP 54	ICRP 54	1 E-05		
49	ICRP 30 (SY ? µm)		ICRP 54	ICRP 54			

Table F7.2.5: Data Handling

Participant ID	Data used for calculation			Handling of measurements below LLD
	Urine	Feces	Organ	
2	all except day 1108	all	all	Measurements below LLD were used as upper bounds for fitted functions.
4	all after day 9000	all after day 8000	Lung and skeleton	n.s.
5	all	all	none	n.s.
6	all	all	lung	Measurements below LLD were used as upper bounds for fitted functions
7	all after day 9000	all	all	Urine measurements below LLD prior to day 9000 were ignored.
8	all after day 9000	all	lung	n.s.
9	all	all	lung	Measurements below LLD were set to 10% of LLD corresponding to 95% confidence
13	selected data (day 1108)	selected data (day 7291)	none	n.s.
14	all	all	all	Measurements below LLD were ignored.
15	all significant after day 9000	all significant after day 9000	lung	Measurements below LLD were ignored.
17	all except days 834 and 1108	all	lung	Urine measurements below LLD were ignored; faeces value of day 8924 was set to 1.5 mBq/d
20	all	all	lung	Measurements below LLD were set to 25% of LLD.
25	all	none	all	Maximum likelihood method (ref..)
27	all	all	all	Value of day 7 was set to 0.
29	all except day 1108	all	all	Measurements below LLD were used as upper bounds for fitted functions.
30	all except day 1108	all	all	Measurements below LLD were set to 80% of LLD.
31	all	all	lung	Measurements below LLD were set to 0 with a standard deviation of LLD.
33	all except day 1108	none	all	Urine measurements below LLD prior to day 9000 were ignored.
34	all except day 1108	all	lung	Measurements below LLD prior to day 9000 were set to 0 +/- LLD; after day 9000 the values given in brackets were used.
32	all	all	all	Measurements below LLD were ignored.
38	all except day 1108	all	lung	Urine measurements below LLD were ignored.
39	all after day 9000	all	all	Measurements below LLD were ignored.
41	all after day 9000	all after day 7000	none	Measurements below LLD were ignored.
42	all	all	all	Measurements below LLD were ignored.
44	all except day 1108	all	lung	Measurements below LLD were ignored.

Table F7.2.5 (continued): Data Handling

Participant ID	Data used for calculation			Handling of measurements below LLD
	Urine	Feces	Organ	
46	all	all	skeleton	Measurements below LLD were ignored.
47	n.s.	n.s.	n.s.	Measurements below LLD were set to 10% of LLD.
48	all	all	all	Measurements below LLD were ignored.
49	all after day 9000	all after day 8900	none	n.s.

Table F7.2.6: Additional information

Participant ID	
2	The ICRP30 lung model compartment g T(1/2) has been adjusted from 500 to 10,000 d; modified distribution factors of 0.7 (bone) and 0.2 (liver) have been assumed.
4	Calculations were made for three different AMAD values (0.1 μm, 1 μm, 5 μm); the resulting dose values are the same within about 10 % whereas the intake values vary by a factor 5; the reported values refer to the default AMAD 5 μm.
5	The dose coefficient is 8.385 E-06 Sv/Bq; the best estimate is assumed to be the average of results based on urine and faecal data.
6	It was assumed that the highest excretion values (days 834 and 1108) correspond to absorption of some material sequestered in tissue as a result of the burnt; the results based on faeces and lung activity were calculated assuming a single inhalation.
7	The best estimate of intake is the mean of urine and systemic organ results.
8	The urine excretion value of day 1108 is considered to be not representative for the intake because the values before and after this day are below the LLD.
9	The individual weight of 105 kg was taken into account.
13	
14	The best estimate is based on weighted average of urine and faecal data; dose coefficient from LUDEP for AMAD 0.1 μm 4.162 E-05 Sv/Bq; alternative assessment for AMAD 1 μm resulted in a dose coefficient 1.531 E-05 Sv/Bq and in committed effective dose values.
15	
17	The dose coefficient is derived from LUDEP as 8.652 E-06.
20	
25	The faecal and organ data were taken into consideration, but not taken into account for the best estimate; the organ data resulted in Pu-intakes of 70000 Bq (lung and lymph-node data); < 5100 Bq (liver data) and 11000 Bq (skeleton data).
27	The three significant values of urinary excretion up to day 1108 were considered as casual events due to biological and other effects; the Am-241 organ burdens were assumed to be completely due to inhalation of Pu-241.
29	IDSS20 and IMIE 3.0 have been used for data fitting.
30	
31	The urine data were considered to be not reliable; the faecal data were considered to be more reliable but also not taken into account for the best estimate; the lung data was assumed most reliable and thus used as best estimate.
32	The committed effective dose value based on faecal data is assumed to be the best estimate.

Table F7.2.6 (continued): Additional information

Participant ID	
33	The result of urine measurement on day 1108 is assumed to be due to external contamination of the sample; all organ data have been used and the activity in the liver is assumed to be at the LLD of 6 Bq; the best estimate is obtained by taking the arithmetic mean of all results.
34	The results of measurements below LLD are set to zero with uncertainty equal to the LLD before day 9227; after day 9227 the values given in brackets are used.
38	The best estimate is obtained as arithmetic mean of the results based on urine, faecal and lung data, respectively; for this purpose the faecal excretion value of d 8923 is set equal to the LLD
39	The measurements below LLD were used as upper limits for the fitting; the urine measurement of day 1108 was assumed to be spurious.
41	
42	Intake via inhalation.
44	The results based on lung data are assumed to be the best estimate;
26	
46	Chronic injection via wound is assumed for modelling the apparent rise in urine activity from 545 to 1108 d; the chronic intake is assumed to stop on day 1108; an alternative calculation for inhalation of type S material results in 20000 Bq intake and 166 mSv committed effective dose.
47	Calculations have been performed for 1 μm and 5 μm AMAD, respectively; the reported values refer to the ICRP 30 default value 1 μm.
48	The results based on faecal data are assumed to be the best estimate.
49	

F7.3 Example I

Assessed by: W P Battersby, BNFL Approved Dosimetry Services, Sellafield, UK

Introduction

This case concerns a radiation worker with exposure many years before an investigation was carried out. Positive urine excretion prompted the investigation, and examination of the person's working history revealed that these positive results were most likely due to an event more than 20 years previously, in 1965. Routine urine sampling had continued over the intervening years, but many results are below limit of detection, possibly due to the higher limits of detection in earlier days. Some in-vivo monitoring data for lungs and lymph, liver, and skeleton are available but the measurements were carried out many years after the incident. Routine faecal samples were also provided, but again, not until many years post incident.

The incident identified was an explosion in a glovebox resulting in burns and heavy facial contamination. The contaminant was freshly separated plutonium, the isotopic composition of which was known.

Basic assumptions

- *Working History*
  With limited information on working history, it has to be assumed that the event in 1965 was correctly identified as the only significant event.
- *Intake Path*
  Pathways via inhalation, ingestion, or direct via burns are all possibilities. Our experience of burns, however, is that the activity tends to remain sealed at the surface and does not lead to systemic uptake. Ingestion cannot be ruled out, but the observed positive urinary excretion would be highly unlikely if this was the only pathway. On balance inhalation was judged the most likely.
- *Solubility*
  The material, freshly separated plutonium, was assumed to be fairly insoluble.
- *Particle Size*
  Since there was an explosion, both large and/or small particles could have resulted. The particle size was therefore varied when performing assessments.

Models and computer tools used for assessments

The models currently used for statutory dose assessment by the Sellafield Approved Dosimetry Service are:

- ICRP30 lung and GI tract models
- ICRP30 Part 4 distribution and retention for plutonium
- Jones model for urinary excretion of plutonium
- ICRP26 tissue weighting factors

In-house software is used , in particular the program PLUTO to calculate intake from urine data. PLUTO incorporates the maximum likelihood method in order to take account of sample results below limit of detection.

Assessment using urine data

A single acute exposure to ICRP30 lung Class Y material was assumed, initially with particle size 5 µm AMAD. The graphical output from PLUTO is shown in Figure F7.3.1. Varying the particle size had some effect on the assessed intake value, but did not significantly improve the fit to the data.

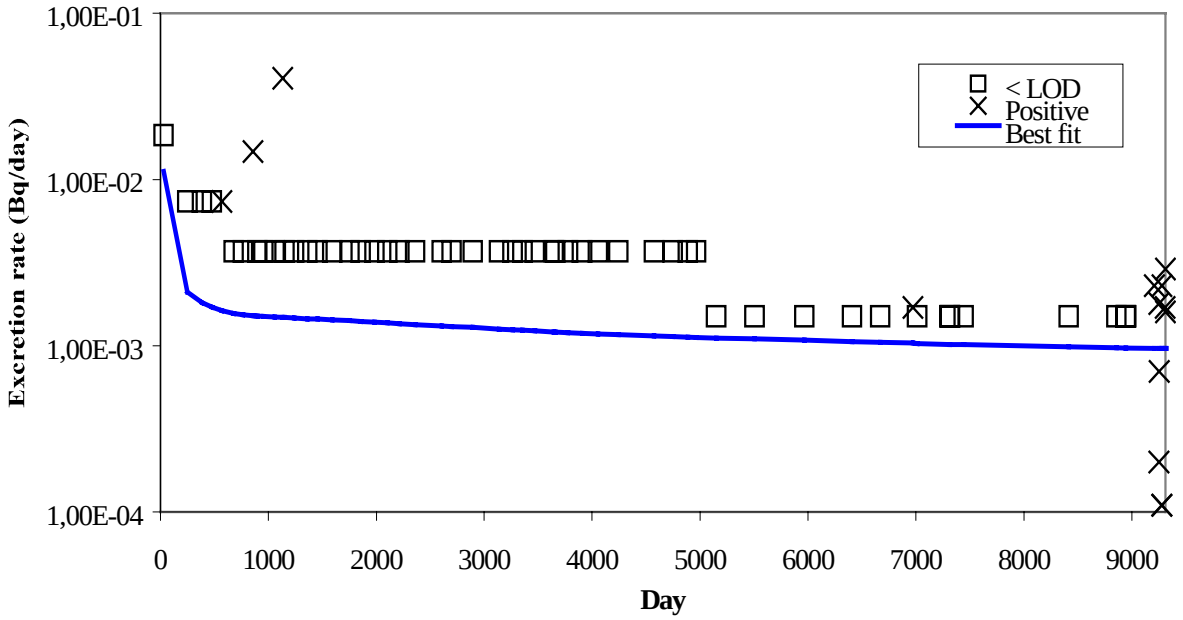

Fig. F7.3.1: Urine Sample Results: Acute intake via inhalation, ICRP30 Class Y, 5 µm AMAD

The result for day 1108 was included, although this result is an order of magnitude larger than those on either side. This was a borderline decision, and had the result been any higher it would have been assumed to be spurious (eg adventitious contamination) and omitted. Omitting the result would have reduced the assessed intake value by approximately 10%.

Table F7.3.1: Intake and dose values based on urine data

Data	Intake Pu239 & Pu240 (Bq)	CEDE Pu239 & Pu240 (mSv)	CEDE Pu241 (mSv)
Urine	3450	120	20

Assessment using faecal data

The samples were provided a very long time post event and will contain

- activity cleared by the lung
- systemic component
- possibly a component due to recent and very much smaller intakes

If the possibility of recent intakes is disregarded, excretion at more than 20 years post intake will be dominated by the systemic component. Using the intake value derived from urine data to predict systemic faecal excretion, the predicted values are in broad agreement with those measured i.e. they are within an order of magnitude of measured values.

It was judged that in this case the faecal data do not provide a good basis for assessing intake > 7000 days earlier; the uncertainties are too great.

Assessments using Am241 organ activity

Intakes based on liver and skeleton data are consistent with the assessment based on urine data. However, none is consistent with those from lung and lymph data, and varying particle size fails to produce better correlation. It was initially thought that some of the measured activity could have been in the ribs and sternum, but apparently the measurements were corrected to take account of this. One possible explanation could be that the material is less soluble than ICRP30 ClassY.

Table F7.3.2: Intake values based on Am-241 organ activity data

Data	Intake * Pu239 & Pu240 (Bq)
Liver	<5100
Skeleton	11000 ± 5600
Lung & lymph	70000 ± 17000

* Uncertainties reflect uncertainties quoted in the organ activity measurements

Minimum detectable activities for the in-vivo measurement system are not given, but the measurement values quoted are very low, and must be near minimum detectable for a 105 kg man. Due to the very large associated uncertainties and the very long elapsed time since the event, the in-vivo data are not regarded as a reliable basis for dose calculation.

Best estimate of dose

The best estimate of dose is judged to be that based on urine data. The other measurement techniques used do not provide a reliable basis for dose calculation due to the long time lapse and large uncertainties involved. These other data do, however, provide some confirmation that the assessment using urine data is a reasonable interpretation.

New models

As from 1 January 2000 regulations will permit the Sellafield Approved Dosimetry Service to use ICRP60 tissue weighting factors, the ICRP66 respiratory tract model and the ICRP67 biokinetic models.

For completeness, assessments were repeated using new models. Slightly better correlation was obtained between intake assessments based on the various measurement techniques, but for the reasons stated above the urine data are still considered to provide the best basis for estimating dose. Assessments for ICRP66 Class S material with a particle size of 5 μm AMAD are shown in Table F7.3.3.

Table F7.3.3: Intake and dose values based on ICRP66 (Type S, 5 μm AMAD)

Data	Intake Pu239 & Pu240 (Bq)	CED Pu239 & Pu240 (mSv)	CED Pu241 (mSv)
Urine	14000	120	12
Faeces	32000	-	-
Liver	<19000	-	-
Skeleton	37000 ± 19000 *	-	-
Lung & lymph	77000 ± 19000 *	-	-

* Uncertainties reflect uncertainties quoted in the organ activity measurements

F7.4 Example II

Assessed by: J. Soegaard-Hansen, Risoe National Laboratory, Denmark

Introduction

Case 7 is a case of real exposure to isotopes of Pu in a nuclear research centre. Significant excretion rates of Pu in a routine monitoring programme in 1990 start an evaluation of the case and an increased monitoring of a the radiation worker involved (male, 29 years old in 1965 and a present weight of 105 kg). The evaluation concludes that the positive excretion samples must be due to an accident on a specific date in 1965 i.e. a single acute intake. In this accident the worker was burnt and heavily contaminated in the face after an explosion in a glove box where Pu was handled. The Pu handled was freshly separated at the time of the accident. The α-composition was 76% ^{239}Pu and 24% ^{240}Pu and the β activity of ^{241}Pu was a factor of 9.7 higher than the total α activity of ^{239}Pu + ^{240}Pu (isotope ratio of ^{239}Pu: ^{240}Pu: ^{241}Pu equals 3:1:39). Routine urine activity excretion rate data were provided in the interval from day 7 to day 9287 after the accident. Faecal activity excretion rates were provided in the interval from day 7290 to 9287 days after the accident. Activity of ^{241}Am in the lungs were provided at days 6952, 7901 and 8917 after the intake. At day 8917 also activity of ^{241}Am in the liver and skeleton were provided.

Exercise problems

The assessors were requested to calculate the total activity intake of ^{239}Pu + ^{240}Pu and the committed effective dose from the total intake. This should be done based on the urine data, the faeces data and the organ data and the best estimate should be stated.

Calculations

Calculations based on excretion rate data

The route of intake was not known, but as an explosion occurred and the face of the person was heavily contaminated and burnt the intake could be by inhalation, by ingestion, through the skin or a mix of these (^{241}Am found in the lungs show that the subject had inhaled activity). In the calculations only intake by inhalation **or** ingestion was considered. The route of intake was selected from the excretion rate functions that gave the best consistency between the urine and faecal activity excretions. The intake was calculated by fitting excretion rate functions to the data. From the intakes the committed effective dose could be calculated.

Calculation of intake:

With the computer programme Ludep (version 2.05) excretion rate function values pr. unit of intake (1 kBq) were calculated assuming the route of intake to be either by inhalation or ingestion and in the case of inhalation assuming either a slow or a medium clearance from the lungs. In the inhalation calculations the activity median aerodynamic diameter (AMAD) was taken to be 5 microns. For the calculation of the urine excretion either an excretion following the Jones function or the Durbin function was considered

Not all excretion data were used to fit the functions. Of the urine activity excretion rate data only the significant values found at times larger than 9000 days after the time of intake were used. The 4 values above LLD found at times <9000 days were excluded because they were "singularities" "surrounded" by non-significant values. They can be due to a cross contamination of the samples, but they can also be real excretions but difficult to take into account. The values with the attribute "might be significant" were also excluded. Of the faecal activity excretion rates also only the significant values were used.

The calculated excretion functions were at first fitted to the excretion rate data by multiplying (scaling) the functions with constants (intake size) so the functions visually fitted the data. The results of these fits are shown in Table F7.4.1.

Table 7.4.1. Scaling factors (intakes) that fit excretion functions to the excretion data. The best consistency between the urine and faecal activity excretions is found for an intake by inhalation where the lung clearance is slow and the urinary excretion is given by the Jones function.

Route of intake, type of clearance from the lungs	Intake (kBq) based on urine data, (J: Jones or D: Durbin excretion function used).	Intake (kBq) based on faecal data
Inhalation, slow clearance	J: 29 D: 77	29
Inhalation, medium clearance	J: 3 D: 15	24
Ingestion	J: 1900 D: 7000	15000

The table shows that the best consistency between the urine and faecal activity excretions is found for an intake by inhalation where the lung clearance is slow and the urinary excretion is given by the Jones function, thus this was chosen to represent the intake, lung clearance and urine excretion. By using Ludeps fitting algorithm the following intakes of ^{239}Pu + ^{240}Pu were calculated:

- intake of ^{239}Pu + ^{240}Pu based on urine activity excretion: 29 kBq ± 3 kBq
- intake of ^{239}Pu + ^{240}Pu based on faecal activity excretion: 29 kBq ± 4 kBq

The uncertainties include only contribution from the fitting procedure. All data points were in the calculations assumed to have the same relative uncertainty. It is estimated that the "true" intake is within a factor of 2 from the calculated values.

Calculation of committed effective dose (CED):

Activity to dose conversion factors (inhalation, AMAD=5 micron, slow clearance) were calculated with Ludep. For ^{239}Pu and ^{240}Pu the factor is 8.647 mSv/kBq and 8.666 mSv/kBq respectively. From an intake I (in kBq) the CED (in mSv) can therefore be calculated from the equation:

$$CED = I \cdot (0.76 \cdot 8.647 + 0.24 \cdot 8.666)$$

Using this equation with the intakes calculated from the excretion data gives:

- CED based on urine activity excretion: 254 mSv ± 26 mSv
- CED based on faecal activity excretion: 251 mSv ± 34 mSv

The uncertainties include only contribution from the uncertainty on the calculated intakes. It is estimated that the "true" CED value is within a factor of 2-3 of the calculated values.

Calculations based on the organ retention data.

The best organ retention data was the lung data and only these were used. An intake was calculated by fitting a lung retention function to the data. From the intakes the committed effective dose could be calculated.

Calculation of intake:

By assuming that ^{241}Am formed from decay of ^{241}Pu is decorporated from the lungs in the same way as ^{241}Pu the ratio R(t) of the ^{241}Pu activity to the ^{241}Am activity at time t after the intake can be expressed as:

$$R(t) = \lambda p/(\lambda a \bullet (\exp(\lambda \bullet t) - 1))$$

where λp and λa are the physical decay rate constants of ^{241}Pu and ^{241}Am respectively. Using this function the ^{241}Pu activity in the lungs were calculated to be: 400 Bq ± 100 Bq (day 6952), 295 Bq ± 82 Bq (day 7901) and 322 Bq ± 67 Bq (day 8917).

The intake of ^{241}Pu was calculated from fitting a lung retention function calculated by Ludep to the three lung contents of ^{241}Pu. Ludep was used to do the fitting and the data point were given the uncertainty from the case description. The retention function was calculated using an intake by inhalation, slow clearance and AMAD = 5 microns, which was found from the excretion data. The calculations on the ^{241}Am data are therefore not totally decoupled from the excretion data. The intake of ^{241}Pu was calculated to be 709 kBq ± 82 kBq. From this the intake of ^{239}Pu + ^{240}Pu could be obtained by dividing by 9.7 to be 73 kBq ± 8 kBq.

Ludep is capable of calculating retention of ^{241}Am from an intake of ^{241}Pu. By using contents. Using this feature and fitting the retention function to the ^{241}Am data an intake of ^{241}Pu was calculated to be 721 kBq ± 85 kBq. From this the intake of ^{239}Pu + ^{240}Pu was calculated to be 74 kBq ± 8 kBq. The uncertainties on the calculated intakes include only the contribution from the fitting procedure. To reflect the uncertainty of using ^{241}Am activity in calculating intakes of ^{241}Pu the uncertainty was estimated to be at least a factor of three larger. Thus the intake could be given as:

- intake of ^{239}Pu + ^{240}Pu based on lung retention of ^{241}Am: 75 kBq ± 30 kBq

It is estimated that the "true" intake is within a factor of 3 from the calculated values.

Calculation of committed effective dose (CED):

Calculating the committed effective dose as described in section 3.1.2 gives:

- CED based on lung retention of ^{241}Am: $6.5 \cdot 10^2$ mSv $\pm$ $2.6 \cdot 10^2$ mSv

The uncertainties include only contribution from the uncertainty on the calculated intakes. It is estimated that the "true" CED value is within a factor of 3-5 of the calculated values.

Best estimates

The intake and committed effective dose calculated from the urine excretion measurements are considered to be the best estimates as they have the smallest uncertainty.

Annex G: Workshop discussion

The following text summarises the discussion by the participants in the closing session of the Workshop.

Comments on this intercomparison exercise and Workshop

The organisers were congratulated on the way in which the results were presented at the Workshop. In previous exercises emphasis had been placed on demonstrating consistency. Here the emphasis was on identifying how differences in assessments resulted from different approaches. This resulted in a wider distribution of results than in previous exercises, and there was a need to explain the reasons for this.

The organisers had spent much time on the issue of identifying outliers objectively. Hopefully this will benefit future exercises. It was considered important to identify outliers on intake assessments as well as on dose assessments. A participant could have a problem with the intake assessment, which is offset in the dose calculation.

A particular problem identified was the inconsistent use of models to assess intake and dose: notably use of ICRP 30 models to assess intake, combined with the ICRP 68 dose coefficient, which is based on ICRP 66 and 67 models.

The next intercomparison exercise

Objectives

It was important to continue the process of analysis established here. However, one aim should be that the results would be closer together. In the year 2000 the new generation of ICRP models (Publications 60/66/67 etc) would be adopted across Europe. The next exercise should therefore be based on the new models.

Procedures

So far as possible results should be given by completing a form: this would help ensure complete responses, and reduce problems with language for non-English-speaking participants. Ideally all results should be filled in boxes. This would be easier for both organisers and participants. (The results forms used here and in recent IAEA exercise were a step towards this.) A further suggestion to make the procedure more straightforward and reduce organisation effort was to construct an electronic database (on a web site), through which results would be entered directly.

It was proposed that the full answers of each participant should be given in an annexe. (This would probably require an electronic document.) This would be useful for study by students or for an experienced assessor when addressing an unfamiliar case, as it would provide a range of approaches, sources of uncertainty, etc.

The proposal that assessments should include an estimate of error was discussed. If so there would be a need to explain how the error was calculated and what contributions to the overall error were included. The organisers might need to define a procedure for estimating errors. There were reservations about this proposal: it was only straightforward to take account of errors from counting statistics, which may not make the largest contribution. To assess errors properly would require a very large effort: there was a need to know distributions of parameter values. A proposed compromise was to identify the major sources of uncertainty.

Cases

It was suggested that examples could be taken from volunteer experiments, with the advantage that the intake is known. However, subjects are often scientists and hence the quality of measurements is not representative of what is obtainable under real plant conditions.

The EURADOS Database of workplace exposures also contained possible examples, including some from the nuclear medicine area. However, there would be a need to obtain more information from the facilities, and the problem of avoiding identification. IAEA recommended setting up database of examples, and would support.

It was pointed out that IAEA may have examples from eastern Europe (Mayak), that recent well-documented cases of tritium ingestion were available in Canada, and that a report on three cases at a Bulgarian NPP had been published recently.

Time frame

There was no specific plan yet, although it was agreed that another was needed. It was proposed that in order to make real progress, there were needs for (1) participants to be able to use the new models and (2) guidelines on internal dose assessment. This might well take 4 – 5 years. Co-ordination with the programme of IAEA exercises should be considered. IAEA plans a regular series, two per year covering both internal and external dosimetry, and including measurements. IAEA exercises try to provide a world-wide service, but only a limited number of participants per country can take part. Countries which had several potential participants were encouraged to conduct their own exercises.

Participation

If participation was again open, there could be over 100 next time. It would need the direct database proposed above to make it manageable.

Guidelines on assessment of internal doses

There was a need to develop principles and guidelines on how to conduct assessments of such cases. However, this could well be a project in itself. IAEA was thought to be preparing a document explaining, step-by-step, how to deal with such data, using examples. At present there are too many models and choices, and lack of guidance on how to apply them. If useful guidelines were developed, there might be no problem with outliers in future exercises.

It was noted that there were no ICRP guidelines on treatment of errors. There was a need to develop guidelines on how to estimate errors on assessed intakes and doses.

Enquiries had been received about monitoring in the medical field. Not much was done and there was a need to look at the situation. However, in the medical field internal doses were much lower than external doses.

Training courses

The latest ERPET course was held in Mol in 1997, and it was not clear who would organise the next one. It was suggested that requests should be directed to Hans Menzel at the CEC, who would initiate another when there was sufficient interest. A course on application of the new models could well be useful. It was proposed that the way forward was (1) develop guidelines (2) give training course (3) conduct intercomparison. However, it was noted that courses were generally for relative beginners (e.g., ERPET) or managers (e.g., IAEA, Prague, June 1999). Such courses would not in themselves prepare someone for participation in such an exercise. However, the exercise cases would be useful as examples for course students, as they have been thoroughly analysed.

Computer codes

It was suggested that there should be a demonstration of the application of different software to the same case at a future meeting.

There was a general enquiry as to which commercially available and evaluated codes use the new generation of ICRP models. GENMOD-PC would be available later this year, but restricted to radionuclides of interest to the CANDU Owners Group (^{3}H, ^{14}C, mixed activation and fission products, about 50 radionuclides). It was hoped to make IDSS commercially available. The most widely used software in this exercise (LUDEP 2) implemented the ICRP 66 respiratory tract model, but ICRP 30 systemic models. The time-scale for a version of LUDEP with ICRP 67 and 69 systemic models was uncertain. It was feasible to implement them, at least for radionuclides without progeny that need independent treatment of systemic biokinetics, but constrained by limited resources. IMBA was available but is not easy to use and has to tailored to requirements of each individual facility, and hence is expensive.

There was a need for software for use in nuclear medicine to determine where activity is located in body. There was also a need for excretion functions, but the behaviour of radio-pharmaceuticals often depends on the specific compound and the radionuclides were short-lived.

EURADOS Database of workplace exposures

In addition to collecting information on documented internal contamination cases, one intended output is to provide information on radioactive materials encountered in practice. This would inform the EULEP group on the materials for which information was needed.

References:

[1] BAP (Bioassay Program). Available: National Radiological Protection Board, Chilton, Didcot, Oxon OX11 0RQ, UK.

[2] BERKOVSKI, V., I. LIKHTAREV, G. RATIA and Y. BONCHUK. Internal Dosimetry Supports System (IDSS) : Multipurpose Research Computer Code. Radiat. Prot. Dosim. 79, 371-374 (1998).

[3] BERKOVSKI, V. Application of the Internal Dosimetry Support System for Interpretation of in vivo and bioassay measurements. In Vivo 99. International workshop. Mol. 1999. Abstract. Paper submitted to Radiat. Prot. Dosim.

[4] BIRCHALL, A., M.R. BAILEY, A.C. JAMES. LUDEP: A Lung Dose Evaluation Programme. Radiation Protection Dosimetry 38, 167-174 (1991)

[5] CINDY (Code for Internal Dosimetry). Available: Canberra Industries, Inc. One State Street, Meriden, CT 06450, USA.

[6] DELTAGRAPH (Version 4.0). Available: DeltaPoint Inc. 22 Lower Ragsdale Drive, Monterey, CA 93940, 1996.

[7] DUNFORD, D.W. and J.R. JOHNSON. GENMOD - A Program for Internal Dosimetry Calculations. AECL-9434, Chalk River Nuclear Laboratories, Chalk River, Ontario (1987)

[8] DURBIN, P.W., Plutonium in man: A new look at old data. In: Radiobiology of plutonium. STOVER, B.J., LEE, W.S., eds. Salt Lake City: The J.W. Press, pp 469-530 (1972)

[9] ECKERMAN, K.F., WARD, R.C, MADDOX, L.B., Radiobiological Bioassay and Dosimetry, ORNL-TM-11858 (1993)

[10] GENMOD-PC 3.0 (Program for Internal Dosimetry Calculations) Available: AECL Research, Chalk River Laboratories, Chalk River, Ontario KOJ, Canada

[11] GIBSON, J.A., BIRCHALL, A.,BULL, R.K., HENRICHS, K., IRANZO, E., LORD, D.J., PIECHOWSKI, J., SOLLETT, E., TANCOCK, N.P., WERNLI,C. A European intercomparison of methods used for the assessment of intakes of intercomparison of methods used for the assessment of intakes of internally deposited radionuclides. Radiation Protection Dosimetry 40:245-257 (1992)

[12] GIBSON, J.A.B., A. ALVAREZ, A. ANDRASI, W.P. BATTERSBY, A. BIRCHALL, C. CHEVALIER, J-P. CULOT, A. ESPINOSA, C. HURTGEN, I. MALATOVA, J.W. MARSH, R.F. PHILLIPS, J. PIECHOWSKI, G.A. ROBERTS and P. STEWART. A Second European Laboratories Intercomparison of Methods Used for the Assessment of Intakes of Internally Deposited Radionuclides. European Commission (to be published).

[13] HALL, R.M., G.A. PODA,R.R. FLEMMING, J.A.SMITH. A Mathematical Model for Estimation of Plutonium in the Human Body from Urine Data Influenced by DTPA Therapy. Health Physics 34, 419-431 (1978)

[14] HUI, T.E., LOESCH, R.M., RADDATZ, C., FISHER, D.R., MCDONALD, J.C. An internal dose intercomparison study. Health Physics 67(3): 217-225 (1994).

[15] HUI, T.E., LOESCH, R.M., MCDONALD, J.C. The second internal dosimetry intercomparison study of the U.S. Department of Energy. Radiation Protection Dosimetry 72(2): 131-138 (1997).

[16] IABM by N.M. MOCANU and A. ENACHE (In house code for intake calculation taking into account multiple bioassay measurements using the algorithms published in NUREG DG-8009 (1993)). Non commercial product.

[17] INDOS (Internal Dosimetry Computer Programs) Available: K.W. SKRABLE, Skrable Enterprises, Inc., 6 Ruthellen Road, Chelmsford, MA 01824, USA.

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, FOOD AND AGRICULTURAL ORGANIZATIONS OF THE UNITED NATIONS, INTERNATIONAL LABOR ORGANIZATION, NUCLEAR ENERGY AGENCY OF THE ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Intercomparison and biokinetic model validation of radionuclide intake assessment, Report of a co-ordinated research project 1996-1998, IAEA-TECDOC-1071, (1999)

[20] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Evaluation of Radiation Doses to Body Tissues from Internal Contamination due to Occupational Exposure. ICRP Publication 10, Pergamon Press, Oxford (1968)

[21] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Alkaline Earth Metabolism in Adult Man, ICRP Publication 20. Pergamon Press, Oxford (1973)

[22] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Recommendations of the International Commission on Radiological Protection, ICRP Publications 26. Annals of the ICRP 1(3) (1977). Elsevier Science Ltd., Oxford.

[23] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Limits for Intake of Radionuclides by Workers, ICRP Publications 30. Annals of the ICRP 2(3/4) (1979). Elsevier Science Ltd., Oxford.

[24] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Individual Monitoring for Intakes of Radionuclides by Workers: Design and Interpretation, ICRP Publications 54. Annals of the ICRP 19(1-3) (1988). Elsevier Science Ltd., Oxford.

[25] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Age-Dependent Doses to Members of the Public from Intake of Radionuclides. Part 1. ICRP Publication 56. Annals of the ICRP 20(2), Pergamon Press, Oxford (1989)

[26] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publications 60. Annals of the ICRP 21(4) (1990). Elsevier Science Ltd., Oxford.

[27] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 2, Ingestion Dose Coef-ficients, ICRP Publications 67. Annals of the ICRP 23(3/4) (1993). Elsevier Science Ltd., Oxford.

[28] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Human Respiratory Tract Model for Radiological Protection, ICRP Publications 66. Annals of the ICRP 24(1-3) (1994). Elsevier Science Ltd., Oxford.

[29] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Dose Coefficients for Intakes of Radionuclides by Workers, ICRP Publications 68. Annals of the ICRP 24(4) (1994). Elsevier Science Ltd., Oxford.

[30] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 4, Inhalation Dose Coefficients, ICRP Publications 71. Annals of the ICRP 25(3/4) (1995). Elsevier Science Ltd., Oxford.

[31] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5, Compilation of Dose Coefficients from Parts 1-4, ICRP Publications 72. Annals of the ICRP 25(1/4) (1995/1996). Elsevier Science Ltd., Oxford.

[32] JARVIS, N.S., A. BIRCHALL, A.C. JAMES, M.R. BAILEY, M.D. DORRIAN. LUDEP 1.0: Personal Computer Program for Calculating Internal Doses Using the New ICRP Respiratory Tract Model. Chilton, Didcot Oxon, UK: National Radiological Protection Board; NRPB-SR 264; 1993.

[33] JARVIS, N.S., A. BIRCHALL, A.C. JAMES, M.R. BAILEY, M.D. DORRIAN. LUDEP 2.04: Personal Computer Program for Calculating Internal Doses Using the ICRP Publication 66, Respiratory Tract Model. Chilton, Didcot Oxon, UK: National Radiological Protection Board; NRPB-SR 287; 1996

[34] JOHNSON, J.R. and M.B. CARVER. A General Model for Use in Internal Dosimetry, Health Physics 41, 341-348 (1981).

[35] JOHNSON, J.R., MYERS, R.C. Alkaline earth metabolism: A model for use in calculating organ burdens, excretion rates and committed effective dose equivalent conversion factors. Radiation Protection Dosimetry 1(2),87-95 (1981).

[36] JONES, S.R. Derivation and validation of a urinary excretion function for plutonium applicable over ten years post uptake. Radiation Protection Dosimetry 11:17-95 (1985).

[37] KATHREN, R.L., HEID, K.R., SWINTH, M.J. C Comparisons of estimates of systemic Pu from uranium excretion. Health Physics 30(5) 487-493 (1987).

[38] LABONE, T.R. A review of some internal dosimetry computer codes Aiken, SC: Westinghouse Savannah River Co., WSRC-MS-91-291 (1991).

[39] LEGGETT, R.W., A Generic Age-Specific Biokinetic Model for Calcium-like Elements. Radiation Protection Dosimetry 41, 183-198 (1992)

[40] LEGGETT R.W., K.F. ECKERMAN, D.E. DUNNING, M. CRISTY, D.J. CRAWFORD-BROWN, L.R. WILLIAMS. On Estimating Dose Rates to Organs as a Function of Age Following Internal Exposure to Radionuclides (AGEDOS), ORNL/TM-8265, (1984).

[41] LEGGETT, R.W, ECKERMAN, K.F., WILLIAMS, L.R, An elementary method for implementing complex biokinetic models, Health Physics, Vol. 64, pp. 260-271, (1993)

[42] LESSARD, E.T., YIHUA, X., SKRABLE, K.W., CHABOT, G.E., FRENCH, C.S., LABONE, T.R., JOHNSON, J.R., FISHER, D.R., BELANGER, R., LIPSZSTEIN, J.L., Interpretation of Bioassay Measurements. Washington DC, U.S. Government Printing Office. NUREG/CR-4884 (1987)

[43] LUDEP 2.0 (Personal Computer Program for Calculating Internal Doses Using the ICRP Publication 66 Respiratory Tract Model, NRPB-SR 297), Updated versions available: National Radiological Protection Board, Chilton, Didcot, Oxon OX11 0RQ, UK

[44] MICROFIT (Fitting code included in INDOS package).

[45] NEWTON, D., HARRISON, G.E., RUNDO, J., KANG, C. and WARNER, A.J, Metabolism of Ca and Sr in late adult life, Health Physics Vol. 59, No. 4, 433-442, (1990).

[46] NRPB-SR 245 (Microcomputer Program to Display Committed Equivalent Organ Doses and Committed Effective Doses from Intakes of Radionuclides) Available: National Radiological Protection Board, Chilton, Didcot, Oxon OX11 0RQ, UK

[47] NUCLEAR REGULATORY COMMISSION AD HOC INTERAGENCY PUBLIC HEALTH ASSESSMENT TASK FORCE. Assessment of the Public Health impact from the accidental release of UF_6 at the Sequoyah Fuels Corporation Facility at Gore, Oklahoma. Washington DC: Nuclear Regulatory Commission; NUREG-1189 (1986).

[48] RAABE, O.G. (Editor) Internal Radiation Dosimetry. Health Physics Society 1994 Summer School. Medical Physics Publishing, Madison, Wisconsin. USA (1994).

[49] RAMSDEN, D., A. BIRCHALL, R.K. BULL, P.P. FOSTER, J.A.B. GIBSON, R. STRONG, N.A. TAYLOR, G.R. TYLER and J. WRAIGHT. Laboratory Intercomparison of Method Used for the Assessments of Systemic Burdens of Plutonium. Radiation Protection Dosimetry 30(2) 95-99 (1990)

[50] RAMSDEN, D., A. BIRCHALL, R.K. BULL, P.P. FOSTER, C.F. HUTTON, J.A.B. GIBSON, R.F. PHILLIPS, G.A. ROBERTS, N.P. TANCOCK, G.E. TENWICK, S. WORMALD AND J.C. WRAIGHT. Laboratory intercomparisons on Internal Dosimetry - Part II. Radiation Protection Dosimetry 42(2) 97-102 (1992)

[51] RBD (Radiological Bioassay and Dosimetry) ECKERMAN, K.F., R.C. WARD, L.B. MADDOX. Report ORNL/TM-11858, Available: Radiation Internal Dose Information Center (RIDIC), Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee 37831, USA

[52] REMEDY (Microcomputer Program for the Evaluation of Radionuclide Intake and Dose from Bioassay or Air Concentration Data). Available: Science Applications International Corporation (SAIC), 10260 Campus Point Drive, San Diego, CA 92121, USA.

[53] SKRABLE, K.W., G.E. CHABOT, C.S. FRENCH, T.R. LA BONE. Intake Retention Functions and their Applications to Bioassay the Estimation of Internal Radiation Doses. Health Physics 55(6) 933-950 (1988)

[54] SS115 (Windows program to access text and data from IAEA Safety Series No. 115) International Basic Safety Standards for Protection against Ionizing Radiation and for Safety of Radiation Sources. Available: International Atomic Energy Agency, Wagramerstrasse 5, P. O. Box 100, 1400 Vienna, Austria.

[55] STATGRAPHICS (Statistical Graphics System). Available: Statistical Graphics Corporation, Manugistics, Inc., 2115 East Jefferson St., Rockville, MD 20852, USA

[56] STRENGE, D.L., R.A. PELOQUIN, M.J. SULA, J.R. JOHNSON. Code for Internal Dosimetry (CINDY), PNL-7493, Pt. 1, Pt. 2, (1990) Northwest Laboratories, Richland, WA, USA.

[57] SULA, M.J., E.H. CARBAUGH, D.E. BIHL. Technical Basis for Internal Dosimetry at Hanford (PUCALC), PNL-6866. R1, Appendix F. (1991) Pacific Northwest Laboratories, Richland, WA., USA.

[58] THIEME, M., E.L. HUNT, K. KÖNIG, A. SCHMITT-HANNIG, R. GÖDDE. The 1995/96 European Intercomparison of in vivo Monitoring Systems. European Commission (to be published)