Monitoring of workers for internal contaminations:  
*The concept of ISO and the approach for the dose assessment*

Klaus Henrichs*,  
Siemens AG, Corporate Radiation Protection and Dangerous Goods Transport, Otto Hahn Ring 6, D 81739 Munich, Germany

**Abstract.** Besides ongoing developments of internal dosimetry other efforts are required to improve the monitoring of workers for potential or real intakes of radionuclides. The disillusioning experience with numerous intercomparison projects identified substantial differences between national regulations, concepts, applied programmes and procedures. Information about measured activities in the body or excretion rates are not always comparable because of severe differences in measuring frequencies and methods, but even results of case studies for dose assessments revealed differences of orders of magnitudes. Besides the general common interest in reliable monitoring results, at least the monitoring of workers sent into various countries (e.g. nuclear power plant services) requires consistent approaches and comparable results. The International Standardization Organization (ISO) therefore initiated projects to standardize the monitoring of workers, the requirements for measuring laboratories and the processes for the quantitative evaluation of monitoring. It is the intention of this contribution to intensify the discussion of the concepts and to promote their practical application.

**KEYWORDS:** Monitoring, dose assessment, internal dosimetry, standardization

1. **Introduction**

Besides the significant progress in internal dosimetry, mainly initiated and compiled by the International Commission on Radiological Protection (ICRP), there still is a need to improve the practical monitoring of workers for potential or real intakes of radionuclides. The disillusioning experience with numerous intercomparison projects identified substantial differences between national regulations, concepts, applied program and methods, and also dose assessment procedures. Measured activities were not comparable because of severe differences between measuring frequencies and methods, but also results of case studies for dose assessments revealed differences of orders of magnitudes. Besides a general common interest in reliable monitoring results, at least the cross-border activities of workers (e.g. nuclear power plant services) require consistency of concepts, procedures, models and practice to ensure the comparability of results.

There were and still are important initiatives to improve the situation:

- the guidelines published by the International Atomic Energy Agency IAEA [1], giving guidance for the assessment of occupational exposures due to intakes of radionuclides,
- an ICRP Guidance Document for the interpretation of bioassay measurements [2],
- various research projects funded by the European Commission:
  - the objective of OMINEX was the improvement of monitoring programs, taking into account the uncertainties of biokinetic models and data [3],
  - the program IDEA tried to improve measuring techniques [4],
  - the program IDEAS developed general guidelines for the evaluation of the committed effective dose on the basis of incorporation monitoring data [5, 6, 7], and
  - the CONRAD (WP5) project (www.bologna.enea.it/Rapporti/CONRAD.pdf) forms a coordinated network for radiation dosimetry to provide a better coordination of research work on the assessment and evaluation of internal exposures [8].

Additionally, standardization projects by the International Standardization Organization ISO (Working Group 13 of TC85 SC2) try to improve the situation by integrating the results of the research projects listed above into simple but reliable standardized procedures.

* Presenting author: E-mail: fs-sek@fs-ev.de
ISO published in 2001 a standard defining the requirements for bioassay laboratories, this standard is presently under revision applying more recent concepts in measurement statistics [9]. In 2008 this draft was sent out for international voting [12].

ISO (2006) adopted a standard, which gives guidance on the design of monitoring programs [10], and

In 2008, a draft [11] was presented for worldwide voting which standardizes the methods to assess exposures on the basis of measured activities (workplace, in vivo or in vitro).

National or international Standards are not mandatory as long as they are not explicitly part of laws and regulations. But they are the basis for internationally compatible rules and procedures, and for certifications and accreditation. Further they generally mean simple and practicable procedures and, to certain degree, legal certainty.

The following will shortly present the regulations formulated in the draft standard on dose assessment [11]. The standards are developed by a group (part of WG13 in TC85 SC2) of experts from ten countries with different backgrounds and professional experience:

Argentina: Ana Rojo,
Austria: Alexander Brandl,
Canada: Bertrand Theriault,
France: Philippe Berard, Catherine Cossonet, Bernard LeGuen, Jean-Rene Jourdain,
Germany: Andreas Dalheimer, Klaus Henrichs (convener),
Italy: Andrea Luciani,
Japan: Takumaro Momose,
Spain: Maria Lopez, Luz Robredo,
United Kingdom: George Etherington, John Gill,
USA: Tom Waters,
IAEA: Rodolfo Cruz-Suarez.

2. General Aspects
The International Standards prepared by the Working Group are developed in order to improve the reproducibility and comparability of dose assessments while at the same time ensuring that the level of effort required for data interpretation is commensurate with the seriousness of the exposure. It should enable the exchange of consistent dosimetric information among laboratories and authorities, including across international borders.

These goals require a clear definition of the purpose of monitoring as well as of quantitative requirements for all procedures, methods and assessments.

2.1 Purpose of Monitoring Programs
The purpose of monitoring in general is to verify and document that each worker is protected adequately against risks from radionuclide intakes and the protection complies with legal requirements. Therefore, it forms part of the overall radiation protection program, which starts with an assessment to identify work situations in which there is a risk of internal contamination of workers, and to quantify the likely intake of radioactive material and the resulting committed effective dose received. Decisions about the need for monitoring and the design of the monitoring program should be made in the light of such a risk assessment.

According to their different purposes and goals, one has to distinguish routine monitoring, special monitoring, confirmatory monitoring and task-related monitoring. All these can be performed for an individual worker (individual monitoring) or they can relate to measurements made in the working environment (workplace monitoring).

Routine monitoring is performed to quantify normal exposures, i.e. where there is no evidence to indicate that acute intakes have occurred; or where chronic exposures cannot be ruled out. Such a program of regular measurements makes it possible to exclude intakes and doses exceeding a certain predefined level. This level should be well below legally relevant limits; selection of the level should take into account uncertainties, for example in activity measurement and dose assessment. If a high value is chosen, intakes representing considerable fractions of dose limits could be overlooked, whilst a
low value may cause the expenditure of unnecessary efforts at low exposures. The basis for routine monitoring programs is the assumption that working conditions and thus incorporation risks remain reasonably constant. Special monitoring is performed to quantify significant exposures following actual or suspected abnormal events. Therefore in comparison to routine monitoring the time of intake is usually much better known and additional information may be available, which helps to reduce the uncertainty of assessment. The purposes of dose assessment in such cases include: to assist in decisions about countermeasures (e.g. decporporation therapy), compliance with legal regulations and aiding decisions for the improvement of conditions at the workplace. In most cases, special monitoring is performed individually. In cases where there is reason to suspect that exposure limits could be exceeded, it may be appropriate to extend the measurements in order to derive individual biokinetic model parameters affecting retention and excretion.

2.2 General Requirements
The International Standards define a set of common requirements concerning
- the design of a monitoring program (monitoring method, frequency of measurements) [10],
- the measurement methods applied (detection limits) [10, 12], and
- the models and data used to assess exposures [11].
The program and the measurement methods must ensure that annual exposures above 5% of the dose limit can reliably be detected. Further, the intervals of routine monitoring programs must be chosen so that the uncertainty of the date of an incorporation event does not result in a significant underestimation of the exposure above a specified factor.
Models and data compiled by the International Commission on Radiological Protection (ICRP) are systematically applied for all derived quantities (frequencies, action levels) and shall exclusively be used for the quantitative interpretation of measured activities.

3. Dose Assessment
Among other activities, WG13 of ISO TC85 SC2 is currently formulating a standard defining the procedure how to assess internal doses on the basis of (in vitro or in vivo) monitoring results [11]. Its use is strictly limited to document compliance with legal regulations; it is not the objective of this project to standardize scientific methods required for the interpretation of individual data e.g. in litigation cases. Its main characteristics will be a stepwise procedure thus balancing the efforts required with the relevance of the individual case. For the majority of routine cases, the dose assessment will make use of reference data tabulated in the standard itself, ensuring a simple and conservative estimate. Only for cases where the results of this first step indicate that a significant intake may have occurred more sophisticated methods will be proposed, which then may be beyond the scope of standardization.
Figure 1 shows the flow chart for the quantitative dose assessment. A similar procedure is described for routine air monitoring.
The essential characteristic is the escalation process depending on the resulting estimated dose and its reliability. The first step for the interpretation of routine monitoring data is a check, whether the conditions of the predefined monitoring program were been observed. In this case, after testing whether the measured activity (in air, body or excreta) may indicate a dose above a pre-defined critical value (maximum 0.1 mSv), a very simple reference method is applied to calculate a first dose estimate. If on this basis a dose above 5% of the annual dose limit can be excluded, the result is accepted without further analysis. For the purpose of this decision uncertainties of the measurement are taken into account (see Clause 4). Above the level of 5% available case specific information is used to improve the reliability of the dose estimate. In combination with an assessment of the uncertainties resulting from the exposure conditions it is then checked if a dose limit may be potentially exceeded. As long as this can be excluded the result is accepted as the (reference) dose for the monitoring interval. Other cases are referred to a more sophisticated assessment beyond the scope of a standard.
Figure 1: Flow chart describing the standard process to assess exposures on the basis of individual monitoring data.
The described process requires taking into account uncertainties of the measurement (see also Clause 4) but later also those resulting from exposure conditions. The procedure for this second type of uncertainty is illustrated in Figure 2 [13, 14].

Graphs of the type shown provide information on the assessed dose in a number of ways. The procedure can be illustrated with reference to the bioassay quantity levels illustrated in the graph (i.e. at A, A*, B, B* and C):

- The measured quantity, A, is below the lower limit of the range. It can then be stated with a high level of confidence that the committed dose $E(50)$ is below the specified dose, D mSv. The minimum and maximum doses that could be assessed from the measured quantity A are $A/B^* \times D$ and $A/A^* \times D$.

- The measured quantity, B, lies between the lower and upper limits of the range. $E(50)$ could be below or above the specified dose, D mSv. The minimum and maximum doses that could be assessed from the measured quantity B are $B/B^* \times D$ and $B/A^* \times D$.

- The measured quantity, C, is above the upper limit of the range. It can then be stated with a high level of confidence that $E(50)$ is above the specified dose, D mSv. The minimum and maximum doses that could be assessed from the measured quantity C are $C/B^* \times D$ and $C/A^* \times D$.

In order to support the user of the International Standard, for relevant nuclides these graphs are given in the annex.

4. Uncertainties

It is important for a dosimetry service to provide information on the uncertainty in assessed doses for two main reasons:

- the reliability of an assessed dose cannot be judged without at least a qualitative indication of the associated uncertainty
- information on the relative contributions to the overall uncertainty in assessed dose may indicate where effort should be placed in order to reduce uncertainty

The restrictions in the scope of the standard, i.e. calculation of reference values, also influences the intensively discussed question of uncertainties and individual variability. Documenting compliance on the basis of reference procedures and assumptions or parameters also means that exclusively uncertainties arising from sampling, measurements and working conditions shall be taken into account.
Other aspects shall only be regarded for the few cases where other than legal aspects play a role, e. g. countermeasures, compensations etc.

The amount of effort expended on assessing uncertainty should be proportionate to the magnitude of the best estimate of the assessed dose, as defined in Table 1.

### Table 1: Reference levels for the assessment of uncertainties in assessed dose

<table>
<thead>
<tr>
<th>Assessed dose, E(50), mSv</th>
<th>Sources of uncertainty to be considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>E(50) ≤ 0.1</td>
<td>None</td>
</tr>
<tr>
<td>0.1 &lt; E(50) &lt; 1</td>
<td>- uncertainty in time or period of intake (routine monitoring)</td>
</tr>
<tr>
<td></td>
<td>- Type A uncertainty in the measured quantity(ies)</td>
</tr>
<tr>
<td></td>
<td>- Type B uncertainties in the measured quantity(ies)</td>
</tr>
<tr>
<td>E(50) ≥ 1</td>
<td>- uncertainty in particle size distribution parameter values</td>
</tr>
<tr>
<td></td>
<td>- uncertainty in absorption classification or absorption parameter values</td>
</tr>
<tr>
<td></td>
<td>- uncertainty in the gastro-intestinal uptake factor</td>
</tr>
<tr>
<td></td>
<td>(in addition to the sources of uncertainty to be considered if E(50) &gt; 0.1)</td>
</tr>
</tbody>
</table>

When a dose is assessed for radiation protection purposes, it is the dose to a reference individual exposed to the specified material under specified conditions that is assessed. This reference individual is described by ICRP Reference Man and ICRP’s biokinetic models for the elements to which the worker may have been exposed. Therefore, uncertainties should only be considered for those model parameters that describe the physico-chemical properties of the material. The following classes of parameters should not be included in any consideration of uncertainties:

- physiological parameters (for example, physical dimensions, organ masses, and breathing rates)
- parameters of ICRP’s Human Respiratory Tract Model, except for those describing the physico-chemical properties of the material
- parameters of ICRP biokinetic models describing systemic behaviour
- parameters describing gender differences
- dosimetric model parameters (for example, absorbed fractions); radionuclide decay data; radiation weighting factors; and, for the calculation of effective dose, tissue weighting factors.

For the quantification of those uncertainties resulting from the measurement itself, the procedure and data are taken from the recommendations developed by the Conrad project mentioned before [8]. The concept makes use of the assumption that the related distributions are log-normal, the confidence intervals are then calculated by multiplying the value of interest by so-called scattering factors. For in vivo-measurements such scattering factors are given in Table 2.

5. Current status and next steps
The described ISO Standard is presently in the so-called DIS-phase (DIS = Draft international standard), which means that the worldwide voting among the member states is expected to be finished at the end of 2008. A final discussion of comments received and of meanwhile collected experience will follow, then the FDIS-voting finishes the process and the Standard will be adopted in 2009. Together with the simultaneously developed International Standard on requirements for measuring laboratories ISO 28218 [12] and the first International Standard on monitoring ISO 20553 [10] this standard forms a set of practicable rules based on common principles, goals, data and models. Its wide use would contribute to considerable improvements and simplifications for monitoring of workers for potential intakes of radionuclides and would enable a reliable exchange of monitoring data and dose assessments.
Table 2: Default values for the lognormal scattering factor SF for various types of measurement from different studies (Type B errors) (derived from [8])

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Type B scattering factor, SF&lt;sub&gt;B&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>True 24-hr urine</td>
<td>1.1</td>
</tr>
<tr>
<td>Activity concentration of $^3$H in urine</td>
<td>1.1</td>
</tr>
<tr>
<td>Simulated 24-hr urine, creatinine or specific</td>
<td>1.7</td>
</tr>
<tr>
<td>gravity normalised.</td>
<td></td>
</tr>
<tr>
<td>Spot urine sample</td>
<td>2.0</td>
</tr>
<tr>
<td>Faecal 24-hr sample</td>
<td>3</td>
</tr>
<tr>
<td>Faecal 72-hr sample</td>
<td>1.9</td>
</tr>
<tr>
<td>Chest count</td>
<td>2</td>
</tr>
</tbody>
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REFERENCES