Good Practice Recommendations

Medical monitoring of occupational internal exposure to radionuclides in nuclear installations

Case Statement

Recommendations made by applying the methodological guide entitled “Clinical Practice Recommendations” published by the Haute Autorité de Santé (HAS)

July 2011

These good practice recommendations have received the HAS label. This label means that the recommendations were prepared according to the methodological procedures and rules promoted by the HAS. All questions or objections concerning the content must be addressed directly to the promoter, the French Occupational Health Medicine Society (SFMT: Société Française de Médecine du Travail).

All of the texts – case statement, short version of the recommendations and information sheets – can be downloaded from the SFMT website (http://www.chu-rouen.fr/pages/Recommendations.php).
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<th>Description</th>
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<tr>
<td>AFNOR</td>
<td>French standards body (Association Française de Normalisation)</td>
</tr>
<tr>
<td>ALARA</td>
<td>As Low As Reasonably Achievable (other denomination: “optimization”)</td>
</tr>
<tr>
<td>AMAD</td>
<td>Activity Median Aerodynamic Diameter (mean particle size)</td>
</tr>
<tr>
<td>ANAES</td>
<td>National Agency for Accreditation and Evaluation of Health Care (Agence Nationale d’Accréditation et d’Évaluation en Santé)</td>
</tr>
<tr>
<td>ASN</td>
<td>Nuclear Safety Authority (Autorité de Sûreté Nucléaire)</td>
</tr>
<tr>
<td>AREVA</td>
<td>French industrial energy group specialized in nuclear power</td>
</tr>
<tr>
<td>BEH</td>
<td>Weekly Epidemiological Bulletin (Bulletin Épidémiologique Hebdomadaire)</td>
</tr>
<tr>
<td>BEIR</td>
<td>Biological Effects of Ionizing Radiations</td>
</tr>
<tr>
<td>“BIOTOX”</td>
<td>Biotoxicological guide for occupational health practitioners (INRS)</td>
</tr>
<tr>
<td>Bq / mBq</td>
<td>Becquerel / millibecquerel</td>
</tr>
<tr>
<td>CDT</td>
<td>French Labor Code (Code Du Travail)</td>
</tr>
<tr>
<td>CEA</td>
<td>French Atomic Energy and Alternative Energies Commission (Commissariat à l’Énergie Atomique et aux Energies Alternatives)</td>
</tr>
<tr>
<td>CERRIE</td>
<td>Committee Examining Radiation of Internal Emitters</td>
</tr>
<tr>
<td>CHSCT</td>
<td>French Health, Safety and Working Conditions Committee (Comité d’Hygiène, de Sécurité et des Conditions de Travail)</td>
</tr>
<tr>
<td>Enlarged CHSCT</td>
<td>This concerns high-risk industrial establishments classified as “high threshold SEVESO” or hosting a civil nuclear installation. The CHSCT committees of such establishments organize meetings, to which designated employees and managers of external contractors are invited, when there is a need to define common safety rules in the establishment and to apply preventive measures. (CIESCT: Inter-Enterprise Health, Safety and Working Conditions Commission - Commission Inter-Entreprises sur la Sécurité et les Conditions de Travail)</td>
</tr>
<tr>
<td>CMR</td>
<td>Carcinogenic, Mutagenic, toxic for Reproduction</td>
</tr>
<tr>
<td>Cofrac</td>
<td>French Accreditation Committee (Comité Français d’Accréditation)</td>
</tr>
<tr>
<td>CSP</td>
<td>French public health code (Code de la Santé Publique)</td>
</tr>
<tr>
<td>DACL</td>
<td>Derived Air Concentration Limit</td>
</tr>
<tr>
<td>DAM</td>
<td>French Military Applications Department (of CEA) (Direction des Applications Militaires)</td>
</tr>
<tr>
<td>Acronym</td>
<td>Full Form</td>
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</tr>
<tr>
<td>DGT</td>
<td>French General Directorate of Labor (Direction Générale du Travail)</td>
</tr>
<tr>
<td>DPUI</td>
<td>Dose per unit intake</td>
</tr>
<tr>
<td>DPUM</td>
<td>Dose per unit content</td>
</tr>
<tr>
<td>DRL</td>
<td>Derived Recording Level</td>
</tr>
<tr>
<td>EDF</td>
<td>Électricité de France (France's national power company)</td>
</tr>
<tr>
<td>EURATOM</td>
<td>European Atomic Energy Community (Communauté Européenne de l’Energie Atomique)</td>
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<tr>
<td>EXF</td>
<td>EXperience Feedback</td>
</tr>
<tr>
<td>GB</td>
<td>Glove box</td>
</tr>
<tr>
<td>Gy / mGy</td>
<td>Gray / milligray</td>
</tr>
<tr>
<td>HAS</td>
<td>French National Authority for Health (Haute Autorité de Santé)</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
</tr>
<tr>
<td>IARC</td>
<td>International Agency for Research on Cancer</td>
</tr>
<tr>
<td>ICPE</td>
<td>Facilities classified for environmental protection (Installations Classées Pour l’Environnement)</td>
</tr>
<tr>
<td>ICP-MS</td>
<td>Inductively coupled plasma mass spectrometry</td>
</tr>
<tr>
<td>ICRP</td>
<td>International Commission on Radiological Protection</td>
</tr>
<tr>
<td>ICRU</td>
<td>International Commission Radiations Units and Measurements</td>
</tr>
<tr>
<td>&quot;IDEAS&quot; (project)</td>
<td>General guidelines for standardizing the assessment of internal dose from monitoring data</td>
</tr>
<tr>
<td>INRS</td>
<td>French National Research and Safety Institute (Institut National de Recherche et Sécurité)</td>
</tr>
<tr>
<td>IPE</td>
<td>Individual Protection Equipment</td>
</tr>
<tr>
<td>IRSN</td>
<td>French Institute for Radiological Protection and Nuclear Safety (Institut de Radioprotection et Sécurité Nucléaire)</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standard Organization</td>
</tr>
<tr>
<td>JO</td>
<td>Journal Officiel (France's official gazette)</td>
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<tr>
<td>LET</td>
<td>Linear Energy Transfer</td>
</tr>
<tr>
<td>Acronym</td>
<td>Definition</td>
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<tr>
<td>LD</td>
<td>Detection Limit</td>
</tr>
<tr>
<td>MBL</td>
<td>Medical Biology Laboratory</td>
</tr>
<tr>
<td>MDD</td>
<td>Minimum Detectable Dose</td>
</tr>
<tr>
<td>MDX</td>
<td>A mixture of uranium and plutonium oxides</td>
</tr>
<tr>
<td>MSE</td>
<td>Medico-Surgical Encyclopaedia</td>
</tr>
<tr>
<td>NI</td>
<td>Nuclear installation</td>
</tr>
<tr>
<td>NCRC</td>
<td>Canadian Nuclear Safety Commission</td>
</tr>
<tr>
<td>NCRP</td>
<td>USA National Council on Radiation Protection and Measurements</td>
</tr>
<tr>
<td>NF</td>
<td>French standard (Norme Française)</td>
</tr>
<tr>
<td>NRBC</td>
<td>Nuclear Radiological Biological Chemical</td>
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<tr>
<td>OHS</td>
<td>Occupational Health Service</td>
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<tr>
<td>Optimization</td>
<td>See ALARA</td>
</tr>
<tr>
<td>PAS</td>
<td>Personal Air Sampler</td>
</tr>
<tr>
<td>PMA</td>
<td>Product Marketing Authorization</td>
</tr>
<tr>
<td>PN</td>
<td>Nasal sample</td>
</tr>
<tr>
<td>RAC</td>
<td>Reference Air Concentration (of radioactivity)</td>
</tr>
<tr>
<td>RBE</td>
<td>Relative biological effectiveness</td>
</tr>
<tr>
<td>RL</td>
<td>Recording Level</td>
</tr>
<tr>
<td>RPO</td>
<td>Radiation Protection Officer</td>
</tr>
<tr>
<td>SEE</td>
<td>Specific Effective Energy = Energy absorbed per unit mass per transformation. (SEE(T→S) is defined as the effective equivalent dose to the target organ T per nuclear decay in the source organ S)</td>
</tr>
<tr>
<td>“SISERI”</td>
<td>Information system for monitoring exposure to ionizing radiation (Système d’Information pour la Surveillance de l’Exposition aux Rayonnements Ionisants)</td>
</tr>
<tr>
<td>SFMT</td>
<td>French Occupational Health Medicine Society (Société Française de Médecine du Travail)</td>
</tr>
<tr>
<td>SFRP</td>
<td>French Society for Radiation Protection (Société Française de Radioprotection)</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<tr>
<td>--------------</td>
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</tr>
<tr>
<td>SPRA</td>
<td>French Army Radiological Protection Service (Service de Protection Radiologique des Armées)</td>
</tr>
<tr>
<td>SSA</td>
<td>French Army medical Service (Service de Santé des Armées)</td>
</tr>
<tr>
<td>Sv / mSv</td>
<td>Sievert / millisievert</td>
</tr>
<tr>
<td>WB</td>
<td>Whole Body</td>
</tr>
<tr>
<td>WG</td>
<td>Working group</td>
</tr>
<tr>
<td>UNO</td>
<td>United Nations Organization</td>
</tr>
<tr>
<td>UNSCEAR</td>
<td>United Nations Scientific Committee of the Effects of Atomic Radiation</td>
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</tbody>
</table>
DEFINITIONS.
DEFINITIONS

The terms used in this guide and in drafting the recommendations are those used in regulatory documents. They may differ from those used in ICRP publications, standards and other guides. The equivalence between the different denominations is stated in the glossary.

The format used here to designate radionuclides is: Symbol-mass number (e.g. Cobalt 60 -> Co-60). Values will be expressed in scientific notation: $3 \times 10^2 = 3 \times 10^0$.

<table>
<thead>
<tr>
<th>Term</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>Absorption and absorption types</td>
<td>Absorption characterized by a rate of transfer of deposited compounds. This rate is designated, depending on the compound, as type F, M or S (fast, moderate or slow), indicating the speed of transfer from the site of deposition in the respiratory tract to the body fluids. Other denominations: solubility, transferability</td>
</tr>
<tr>
<td>Actinides</td>
<td>Name given to chemical elements of atomic number 89 to 103 in the periodic table of elements</td>
</tr>
<tr>
<td>Activity</td>
<td>The activity $A$ of a quantity of a radionuclide in a given energy state at a given time is $\frac{dN}{dt}$, where $dN$ is the probable number of spontaneous nuclear transitions from this energy state accompanied by emission of ionizing radiation over an interval of time $dt$. Activity is expressed in becquerels (Bq).</td>
</tr>
<tr>
<td>Activity Median Aerodynamic Diameter (AMAD)</td>
<td>Value of the diameter in an aerodynamic particle (aerosol) size distribution for which the total activity of particles larger than and smaller than this AMAD size are equal (&quot;mean particle size&quot;)</td>
</tr>
<tr>
<td>ALARA</td>
<td>See optimization</td>
</tr>
<tr>
<td>Ca-DTPA</td>
<td>Calcium diethylenetriaminepentaacetate. A sequestering agent acting on plutonium and americium and thereby protecting target organs</td>
</tr>
<tr>
<td>Committed effective dose (E50)</td>
<td>Effective dose accumulated over 50 years after intake for workers.</td>
</tr>
<tr>
<td>Contamination</td>
<td>Contamination of any material, surface, medium or person by radioactive substances. In the particular case of the human body, this radioactive contamination includes both external dermal contamination and internal contamination via any route.</td>
</tr>
<tr>
<td>Decision threshold</td>
<td>Invariable value of a mesurand quantifying a physical effect which, when exceeded by the value of a measurement of the mesurand, means that the physical effect actually exists</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
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</tr>
<tr>
<td>Deposition</td>
<td>Deposited radioactive matter, expressed as a percentage of the initially deposited activity</td>
</tr>
<tr>
<td>Detection limit</td>
<td>The smallest true value of a measured that it is possible to detect using a given measuring method</td>
</tr>
<tr>
<td>DPUI</td>
<td>See h(g)</td>
</tr>
<tr>
<td>Dose-benefit</td>
<td>Percentage of dose avoided thanks to therapeutic action (relative to the dose that would have been received without treatment)</td>
</tr>
<tr>
<td>Effective dose (E)</td>
<td>Sum of the tissue-weighted equivalent doses due to internal and external exposure of relevant body tissues and organs, as defined in the Decree corresponding to Article R.231-80 of the French Labor Code. The effective dose is expressed in sievert.</td>
</tr>
<tr>
<td>f(t) excretion</td>
<td>Fraction of incorporated material eliminated from the body in excreta (urine or faeces) at a time t after intake</td>
</tr>
<tr>
<td>f(t) retention</td>
<td>Fraction of incorporated material retained in the body, a tissue, a target organ or a body region at a time t after intake</td>
</tr>
<tr>
<td>Gray</td>
<td>Unit used to express absorbed dose of ionizing radiation. It measures the energy released in a unit mass of matter. One gray corresponds to the absorption of one joule of ionizing radiation by one kilogram of matter</td>
</tr>
<tr>
<td>Half-life</td>
<td>See period</td>
</tr>
<tr>
<td>h(g)</td>
<td>Coefficient of committed effective dose per unit intake. Formerly called DPUI</td>
</tr>
<tr>
<td>Intake</td>
<td>Refers to radioactive nuclides entering the body from the environment. There are 3 main intake routes: inhalation, ingestion and dermal (percutaneous or transcutaneous, via wounds)</td>
</tr>
<tr>
<td>Optimization</td>
<td>The lowering of the dose to the lowest level reasonably achievable (the dose-benefit must remain reasonable relative to the required investment and the negative aspects of certain measures, such as the constraints associated with wearing individual protection equipment)</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<td>-------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Period (or half-life period)</td>
<td>Time after which the initial radioactivity falls by half</td>
</tr>
<tr>
<td>Monitoring programme</td>
<td>The entire approach, from the risk analysis through to validation of the defined monitoring procedure</td>
</tr>
<tr>
<td>Monitoring protocol</td>
<td>One aspect of a radiological monitoring programme concerning medical responsibility, in particular prescription</td>
</tr>
<tr>
<td>Radiological cleanliness</td>
<td>Term relating to the state of a nuclear facility</td>
</tr>
<tr>
<td>Radionuclide (radioactive nuclide)</td>
<td>An atom that is naturally or artificially radioactive</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>The standard deviation is dependent on the logarithmic-normal (&quot;lognormal&quot;) distribution of measurements on biological samples</td>
</tr>
<tr>
<td></td>
<td>See scattering coefficient</td>
</tr>
<tr>
<td>Scattering coefficient</td>
<td>Standard deviation of the lognormal distribution of the measurements on biological samples</td>
</tr>
<tr>
<td>Transferability</td>
<td>See absorption</td>
</tr>
<tr>
<td>Transuranic (elements)</td>
<td>Chemical elements of the periodic table of elements having an atomic number greater than 92 (uranium), for example plutonium</td>
</tr>
</tbody>
</table>
FIRST PART.

Working method
1. **CHOICE OF THE WORK SUBJECT**

The choice of the subject takes into account the difficulties expressed by occupational health services (OHS) in providing the medical-professional monitoring of workers in nuclear base (i.e. fixed) installations (NI) facing a risk of internal exposure to radionuclides.

The monitoring responsibilities of occupational health practitioners are to:
- implement monitoring programmes based on an analysis of risks at the workplace;
- evaluate doses (committed effective doses) based on monitoring results, and archive these results in the occupational health medical file;
- evaluate the impact on workers’ health, to enable them to reply to workers’ questions and prescribe psychological support following exposure, if necessary.

This subject is the object of many varied recommendations and publications (identified and described in the chapter “Documentary Search”), but these are insufficient:
- The standards and publications of the International Commission on Radiological Protection (ICRP) are supposed to be applicable in all countries, under all regulations and in the majority of operational contexts. To a lesser degree, the same can be said of the IDEAS and OMINEX guidelines (see § 4-1-5 First Part). This universality prevents these guidelines from being extremely precise or directive.
- Few publications are available, in particular in the international literature, on the specific aspects of practical implementation of individual monitoring in NIs.

In short, neither the regulations nor the international and normative recommendations enable a method to be defined precisely and pragmatically. These documents alone cannot provide a baseline directly applicable in daily practice.

2. **METHOD FOR CLINICAL PRACTICE RECOMMENDATIONS**

2-1. **Expression of the need for recommendations = object of the referral**

Practicing occupational health practitioners often find it difficult to understand and adapt to the method of assessing committed effective dose following internal exposure. This assessment is difficult despite an abundance of literature and scientific data on the subject.

Professional meetings and interchanges with experts have enabled the problems encountered in current practice to be identified:
- The method used to evaluate the dose based on test results must be explained.
- An approach used to evaluate dose consistency is not defined.
- Exposure data is sometimes difficult to obtain.

In particular, the physico-chemical and radiological parameters of radioelements: what do we do when these are incomplete, or even absent?
- The traceability of dose assessments is not formalized.

The recording of a dose following internal exposure is not sufficient to ensure satisfactory traceability. Precise data must be available to
recalculate the dose later, following scientific progress or a legal request. Yet in reality the method used and the parameters taken into account are rarely stated. Occupational health practitioners enter the data in different ways in their medical files.

- The method of integrating assessed doses in the accumulated dose is not explained.
- The significance of the dose in terms of health risk must be explained to the workers concerned.

It is not easy to translate the international recommendations and studies of the health hazards of ionizing radiation into a clear expression of individual risk.

#### 2.2. The HAS method for clinical practice recommendations

We decided to follow the “Clinical Practice Recommendations” (see ref. ANAES, 2000) method proposed by the HAS.

This method was chosen in view of the scope of the challenge and the number of questions that it raises, in addition to the abundance of regulatory references and literature often having a high level of evidence.

The issues dealt with are the object of discussions, often at expert level, between the professionals concerned, although they are not controversial enough to justify a public debate.

The steps involved in writing recommendations are:

1. Define the objective of the recommendations and the questions to which they must reply.
2. Review the literature and assign levels of evidence:
   - synthesize the data taken from all of the normative and international documents;
   - analyse the data taken from scientific publications and multidisciplinary working groups;
   - take into account feedback from real clinical cases.
3. Write an initial version of each recommendation and assign a grade.
4. Analyse the formalized opinions (scores, comments) after examination by the Reading Group.
5. Write the final version of the recommendations.

These recommendations have been developed independently, following a preliminary discussion with the HAS, then regular information on the progress of the work (successive versions of the recommendations and meeting reports). There were numerous interchanges with a project leader in the Professional Practices Department, in order to make some necessary methodological adjustments.

**PROMOTING ORGANIZATIONS**

**MAIN PROMOTER**

The French Occupational Health Medicine Society (SFMT: Société Francaise de Médecine du Travail) presided by Prof. Patrick Brochard until 2010, then by Prof. Catherine Nisse.

This project is conducted in the framework of an agreement made in early 2010 between the French General Directorate of Labor (DGT) and the SFMT to formulate recommendations on occupational health practices, with the aim of providing a basis for future regulations.

**JOINT PROMOTERS**

Occupational health practitioners responsible for coordinating occupational health services in nuclear industries:
- AREVA
  - Dr. Alain Acker – Medical director
  - CEA
  - Dr. François Pic – Medical coordinator
  - EDF
  - Dr. Dominique Folliot – Coordinating medical officer
  - SPRA
  - Prof. Pierre Laroche – Deputy – Director of the Army Radiological Protection Service

The work organization for this project, up until the final version of the recommendations, was monitored by the SFMT President and by the four "coordinating medical officers".

**WORKING GROUP**

The Working Group (WG) was multidisciplinary and representative of the various fields of expertise and professional practice concerned by the subject:
- Field practitioners (occupational health practitioners and biologists) having experience of cases of internal exposure in NIs.
- Experts representing the different specializations involved (employee monitoring, treatment, dose assessment, etc.) and having worked in learned societies, working groups or official organizations (IAEA, AFNOR, ICRP, Cofrac, ISO, IRSN, SFMT, SFRP).

This Working Group had no president. It was coordinated by representatives of the field professionals and the experts:
- Dr. Nicolas Blanchin (CEA – occupational health practitioner) and Dr. Benoit Quesne (AREVA and CEA – occupational health practitioner),
- Philippe Bérard (CEA – expert) and Dr. Michèle Gonin (EDF – occupational health medical advisor)

It convened regularly: 20 plenary meetings (30 days), plus meetings in sub-groups (6 for the field professionals, 10 for the experts).

The critical analysis and synthesis of the data found in the literature were done mainly by the expert sub-group.

The work of the field professional sub-group was to define and formulate recommendations based on their examination of the documents written by the expert sub-group, taking into account, in the absence of scientific evidence, their own clinical experience. The plenary sessions enabled all of the case statements and recommendations to be validated.

**WORKING GROUP COMPOSITION**

In alphabetic order:

**GROUP COORDINATION**

M. Philippe Bérard
(CEA/Fontenay Aux Roses – Life Sciences Department - expert)
Dr. Nicolas Blanchin  
(CEA/Cadarache – occupational health practitioner)
–
Dr. Michèle Gonin  
(EDF Saint-Denis – nuclear production – occupational health medical advisor)
–
Dr. Benoit Quesne  
(AREVA and CEA/Marcoule – occupational health practitioner)

GROUP MEMBERS

Occupational health practitioners:
Dr. Anne-Laure Agrinier (CEA/Marcoule), Dr. Laurent Bourgaut (CEA/Saclay)
–
Pharmaceutical biologist:
M. Robert Fottorino (CEA/Cadarache)
–
Experts:
IRSN/Paris: M. Eric Blanchardon, Dr. Cécile Challeton de Vathaire, M. Didier Franck
–
CEA/Fontenay Aux Roses:
M. Jean Piechowski
–
CEA/DIF (Parisian region):
M. Paul Fritsch, M. Jean-Luc Poncy

READING GROUP

The members of the Reading Group were chosen to be representative of the different fields involved in the subject and the professionals concerned by these recommendations.

Of the 59 people solicited, 40 replied. Each member of the Reading Group responded personally, not institutionally. This group was composed of:
– occupational health practitioners monitoring workers exposed to ionizing radiation (20)
– pharmaceutical biologists (6)
– radiation protection specialists (2)
– French experts (5) and foreign experts (1)
– university medical professors and doctors (3)
– representative of the Nuclear Safety Authority (1)
– representative of employers (1)
– representative of employees (1)

The composition of the group is detailed in Appendix 1.

SUCCINT RESULTS OF THE READING GROUP

The Reading Group had to report within 4 weeks, giving three opinions:
– Relevance, justification: Is the recommendation supported by pertinent references or solid arguments? Is there an explicit link between the proposed recommendation and the case statement?
– Clarity, presentation, legibility: Is the recommendation written in a simple, clear and precise language?
– Application feasibility: Can the recommendation be implemented without major impact on the organization?

A scoring scale of 1 to 9 was used:
– 9 = full agreement
– 1 = total disagreement

128 recommendations were proposed, some of them broken down into several parts in order to enable the readers to provide more pertinent opinions.

The breakdown of the overall appreciation was as follows:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>All 4 subjects</td>
<td>17</td>
<td>24</td>
<td>72</td>
<td>91</td>
<td>312</td>
<td>380</td>
<td>881</td>
<td>2401</td>
<td>10664</td>
</tr>
<tr>
<td></td>
<td>0.11%</td>
<td>0.16%</td>
<td>0.49%</td>
<td>0.61%</td>
<td>2.10%</td>
<td>2.56%</td>
<td>5.94%</td>
<td>16.18%</td>
<td>71.85%</td>
</tr>
</tbody>
</table>

SCORING RESULTS TOPIC A

- Relevance
- Legibility
- Feasibility

1 Total number of replies for the scoring level of all of the recommendations and of the 3 opinions
2 Percentage of all replies
Overall, the subject and its content were considered to be useful and relevant, in particular given the lack of any existing document of the same nature.

The final text, taking into account the Reading Group’s opinions, was written after discussion of the comments made:
– Each recommendation was reviewed whenever at least one score was less than 7 and/or when the related comments called for a discussion.
– Some recommendations were either removed and their content integrated into the case statement, or completely reformulated.

2-3. | Presentation of the recommendations

**OCCUPATIONAL HEALTH PRACTITIONERS**

The recommendations will be presented during meetings with occupational health practitioners, organized as part of their continuous medical training, or at professional congresses.

All of the texts will be made available in electronic version on the SFMT website and on the company intranets.

The complete text will be widely distributed to all occupational health practitioners concerned and may be the subject of a special issue of a professional journal.

**PERSONNEL OF NUCLEAR INDUSTRIES**

The recommendations will be presented to Health, Safety and Working Conditions Committees (CHSCT).

They will be used during information sessions about workers’ risks.

An information document written by the Working Group will be prepared for use in the establishments’ waiting rooms (paper version) and intranets (electronic version).

**PERSONNEL OF COMPANIES WORKING FOR NUCLEAR INDUSTRIES**

The recommendations will be presented to external companies working on nuclear sites (enlarged CHSCT or CIESCT).

An information document written by the Working Group will be prepared for use in the establishments’ waiting rooms (paper version and posters) and intranets (electronic version) accessible by contractors.
2-4. | Grading of the recommendations

The literature is analysed using the method and the levels of evidence recommended by the HAS (see ANAES guide, 2000), adapted to the specificity of the subject being dealt with, for the purpose of grading the recommendations. To do this, a correspondence matrix was prepared showing the type of article chosen, the level of evidence according to the ANAES guide and the grade of the recommendations to be set forth (see below).

The recommendations made on the basis of regulatory references are not graded (this will be indicated by an annotation).

The recommendations made on the basis of normative references and international recommendations are considered to have a high level of evidence, which justifies the Grade A assigned to them.

Given the lack of data in the literature, the recommendations made are based on a professional agreement justified by clinical feedback on professional practices and clinical cases.

### CORRESPONDENCE MATRIX BETWEEN THE TYPE OF ARTICLE CHOSEN, THE LEVEL OF EVIDENCE ACCORDING TO THE ANAES GUIDE AND THE GRADING OF THE RECOMMENDATIONS:

<table>
<thead>
<tr>
<th>ARTICLE TYPE</th>
<th>SELECTION CRITERIA *</th>
<th>LEVEL OF EVIDENCE **</th>
<th>GRADE OF THE RECOMMENDATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific article, with reading committee, on human data for professional exposures in NIs</td>
<td>a. Cases &gt; 10 or b. Period &gt; 5 years or c. Event &gt; 5 or d. Good</td>
<td>2</td>
<td>Grade B</td>
</tr>
<tr>
<td>Scientific article, with reading committee, on human data for professional exposures in NIs</td>
<td>a. Cases &lt; 10 and b. Period &lt; 5 years and c. Event &lt; 5 and d. Incomplete</td>
<td>3 – 4</td>
<td>Grade C</td>
</tr>
<tr>
<td>1. Scientific article, with reading committee, on characterization data at the workplace</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Scientific article, with reading committee, on human data for exposure to natural radionuclides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Scientific article, with reading committee, on animal data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Scientific article, with reading committee, on theoretical models or methodological approaches</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Scientific article, without reading committee, on human and animal data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Proceedings of congresses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Theses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Unpublished data – Reports – Personal data</td>
<td></td>
<td></td>
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</tbody>
</table>

2-5. | Update of the recommendations

These recommendations are established in a given context of scientific knowledge for the period 2011-2016.

They must be updated to take into account future scientific progress and the concomitant changes in the regulations, as well as feedback on professional practices.

* Selection criteria: a. Number of cases; b. Observation period; c. Number of events; d. Exposure characterization

** Level of evidence according to the ANAES guide 2000
3. | MANAGEMENT OF CONFLICT OF INTEREST

All members of the Working Group were volunteers and received no specific remuneration for this work. The time spent on writing by working group members was taken from their normal professional activity.

The only contribution of employers was to authorize the participation of the project members and to bear their logistic expenses, including travel expenses and the provision of meeting rooms and secretarial services.

The participants’ employers exerted no influence whatsoever during the progress of the project. All of the group members declared that they have no conflict of interest in regard to this subject.

4. | SUMMARY

French regulations assign responsibility for the individual monitoring of internal exposure and the dose and health assessment to occupational health practitioners at nuclear installations.

However, the creation of monitoring programmes and the understanding and appropriation of the method of evaluating the committed effective dose following internal exposure remains difficult, despite an abundance of literature and scientific data.

The objective of these recommendations based on scientific knowledge and feedback on professional practices is to optimize the prevention of internal exposure risks and the dosage and medical monitoring of workers exposed to this risk.

Emphasis is placed on harmonizing professional practices and improving the traceability of exposures and the actions to inform exposed workers.

The method chosen to develop our recommendations is the one used by the HAS for clinical practice recommendations.

5. | DOCUMENTARY SEARCH

5-1. | Information source

The search for data in the literature took into consideration the following points:

– The subject dealt with is the object of numerous international recommendations serving as a basis for regulations and normative references.

– The international recommendations must be supplemented by a review of literature published later than the recommendations, in order to identify new issues, problems and research results.

INTERNATIONAL ORGANIZATIONS PUBLISHING INTERNATIONAL RECOMMENDATIONS

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the Committee on the Biological Effects of Ionizing Radiation (BEIR) evaluate scientific studies. These committees publish bibliographic reviews regularly.

The International Commission on Radiological Protection ICRP publishes recommendations based on these reviews. The latest ICRP recommendations are discussed by various expert groups then re-transcribed:

– either at international level, for example as basic radioprotection standards or practical guides published by the International Atomic Energy Agency (IAEA),

– or into European law, then into French law.

This rather special scheme, in which international recommendations are discussed at several levels before being adopted, then transcribed into national law, ensures that all scientific and technical elements likely to influence the very nature of the recommendations are taken into account. The recommendations become de facto radioprotection references; they are reviewed periodically in the light of new scientific information and are validated by the scientific community.

OUR RECOMMENDATIONS ARE BASED ON REFERENCES DRAWN FROM:

– French regulations,


– reports from international organizations (UNSCEAR, BEIR, etc.),
– international recommendations (mainly ICRP),
– reports from European and national working groups,

– the analysis of the literature.

5-1. Regulations

These regulations define the general framework and rules to be respected, but they usually do not define methods of practical implementation.

5-1-2. Standards

Standards contain requirements enabling the practical achievement of objectives defined by regulations and international recommendations. They are published by the International Standard Organization (ISO), or by the AFNOR for the French version (“NF”: Norme Française). The drafting of international standards is delegated to ISO technical committees. Some international government and non-government bodies also collaborate with the ISO in this work.

In relation to our subject of interest, two main standards were used:

ISO 20553 (2006) standard entitled “Radiation protection - monitoring of workers occupationally exposed to a risk of internal contamination with radioactive material”, written by the technical committee TC 85 and its sub-committee SC2. This international standard specifies the minimum requirements for evaluating the professional monitoring data of workers exposed to risks of internal radiocontamination. It proposes procedures and hypotheses useful for standardized interpretation of monitoring data, in order to obtain acceptable reliability. These procedures enable exposures to be quantified, in order to document the compliance with regulatory and radioprotection programme requirements. It defines the limits of applicability of these procedures, in terms of dose levels above which more sophisticated methods must be used.

The author reminds us in a preface that the ISO has run projects aimed at standardizing the monitoring of workers, laboratory measurement requirements and processes used for quantitative evaluation of monitoring data. The article is an introduction to certain important aspects covered by these standards: the necessity and design of a monitoring programme, the methods and intervals, reference levels and dose assessment approaches. It also underlines the general common interest of having reliable monitoring results, at least in sectors involving transborder activities (e.g. nuclear power plants), which imposes consistent approaches and comparable results.


The article by E. Fantuzzi and al in 2004 [67 – Level of Evidence 4] is a synthetic article that collates information on the use of all of the standards applied in individual monitoring practices, from dosimeter calibration to the quality assurance procedures to apply to the global dose assessment procedures. The authors remark that a large number of standards on radioprotection and individual monitoring have been published by national and international organizations and are available. These are supplemented by quality assurance standards, covering both the technical aspects and the management of a dosimetry department. The authors emphasize that:
– the application of the standards is not mandatory and, consequently, different European countries apply them to different degrees;
– however, for a number of good reasons, it would be preferable to seek harmonization of individual monitoring requirements and procedures within the European Union (EU).
This harmonization does not mean that the procedures must be identical, just that they must satisfy the same general requirements and that their results should be comparable.

The authors provide a list of documents relating to subjects, such as individual monitoring recommendations and requirements, whose application could contribute to the harmonization of procedures.
5-1-3. | International organizations

1. UNSCEAR (UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION)

The UN General Assembly created this committee in 1955. Its mandate within the UN system is to evaluate the levels and effects of radioexposure and to report on this subject. For governments and organizations worldwide, the committee’s assessments provide a scientific basis for evaluating irradiation risks and adopting safety measures. Since its creation, the UNSCEAR has published only 16 major studies, but these are fundamental information sources. Its latest publication is the UNSCEAR 2006 Report [2-32]: “Sources and effects of ionizing radiation”.

2. AMERICAN ACADEMY OF SCIENCES (BEIR COMMITTEE)

This committee dedicated to the biological effects of ionizing radiation advises the American government on the relations between radioexposure and health risks. Its latest publication is BEIR VII in 2006 [2-34]: “Health risks from exposure to low levels of ionizing radiation”.

3. INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)

This independent international organization was created in 1957 under the aegis of the UNO; its headquarters are in Vienna, Austria. Its role is to encourage the exchange of technical and scientific information in the atomic energy field. It prepares guides, reports and basic standards.

4. NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS (NCRP)

NCRP reports provide a basis for American legislation.

NCRP Report 161 [2-21; 2008] makes recommendations on the medical management of incidents and accidents resulting in radiocmonamination. These recommendations take into consideration victims exposed in a professional environment and incidents affecting large numbers of people. This report is an update of NCRP Report 65. It includes two volumes:

- A four-part guide providing information immediately applicable at the site of the incident. Part 1 provides reflex sheets supplemented by more detailed information in the rest of the report. Part 2 describes medical and radioprotection actions to be taken at the site before transportation of victims to hospital. Part 3 describes measures to be taken at the hospital. Part 4 makes recommendations on medical follow-up of people having been exposed to radionuclides.

- Scientific and technical bases underpinning the guide. This volume, including 7 chapters and 10 appendices, is particularly useful in that it collates information taken from many other sources in a single volume. It can be used as a training support, notably for medical personnel who intervene in nuclear emergencies.

NCRP Report 156 [2-20; 2007] assembles information on observed human and animal experiments, to enable modelling of the local and system kinetics of radionuclides deposited in wounds and to evaluate doses. Although more than 2,100 cases of wounds are reported, the majority concerning incidents involving actinides, the authors base their modelling essentially on well-controlled animal experimental data, since human cases are too few to be exploited due to medical and surgical interventions that interfere with the kinetics. The report provides information to help practitioners to interpret the results of their measurements, to evaluate doses and to guide their therapy.

Kinetic models and detailed dosimetry factors can be used, but since a wound is not a physiological model these cannot be considered to be reliable and must be used only for orientation purposes.

5-1-4. | International recommendations

International Commission on Radiological Protection (ICRP)

This commission is an international non-government organization whose scientific members are appointed intuitu personae on the basis of their scientific work, expertise and reputation.

Only experts who have no conflict of interest with the world of radioprotection are chosen. They make recommendations on radioprotection issues, defining for example annual dose levels not to be exceeded, dose calculation methods and tools, as well as radiological risk management methods.

ICRP publications provide a basis for European directives that are later transposed by each EU Member State into national law.

The main publications concerning the monitoring of exposed workers are:

Publication 60 [2-6; 1990], which provides orientations regarding the fundamental principles on which effective radiological protection can be based. It is consistent with the French regulations in 2011.

Publication 75 [2-12; 1997] provides advice on good practices in the application of ICRP principles for radioprotection of workers. It is consistent with Publication 60.

Publication 78 [2-13; 1998], which provides a general guide for implementing individual monitoring programmes and for interpreting the results of estimated intakes of radionuclides by workers. It is based on the general principles of Publication 75.

Publication 103 [2-17; 2007], which is a revision of Publication 60. It updates, consolidates and develops the complementary
1. IDEAS guidelines [56 - 2006]

These guidelines are the result of a research project entitled “General guidelines for the estimation of committed dose from intake monitoring data”, and dubbed “IDEAS”, conducted from 2001 to 2005 as part of the European Commission’s 5th Framework Programme for Research and Technological Development (FPRTD). Internal dosimetry experts and 8 institutions in 7 European countries participated. The project started by creating two databases of internal contamination cases: one base of bibliographic data (“BibDb”) with 500 references and a database of descriptions of more than 200 cases of internal contamination (“IntContDb”).

Next, 67 cases representing varied exposure circumstances and 16 radionuclides were selected and evaluated using IMIE [Berkovski and al 2007 – 9 – Level of Evidence 3] and IMBA-Expert [Birchall and al 2003 -1998-2007 ; 17 – 16 – 19 – Levels of Evidence 4), with at least two experts making different hypotheses using the same software.

The best calculated estimations of intake and committed effective dose were given for each case, accompanied by notes on important issues in the writing of the IDEAS guidelines.

The guidelines describe the ICRP biokinetic models at the time of the Publication 78 and their adjustable parameters.

– They propose a quantification of measurement uncertainties by a scattering factor and give statistical tools to judge the consistency of measurements with the chosen model and the most plausible intake value.

– A standardized procedure for evaluating committed effective dose is structured via logical diagrams with four levels of complexity according to the order of magnitude of the expected dose.

The guidelines are validated by means of an intercomparison exercise of calculated internal doses organized jointly with the IAEA and open to experts worldwide [Hurtgen and al 2007 – 98 – Level of Evidence 4], which reveals that their use reduces the scattering of dose assessments.

Looking beyond their use in the framework of the IDEAS project:


– the evaluations were compiled into an evaluation database (“EvalDb”) connected to the IntContDb internal contamination database; they were also analysed to highlight the hypotheses commonly made in similar scenarios, the models and parameters used, and the procedures employed to estimate uncertainties and manage deviant data and measurements lower than the detection limit.

5-1-5. | European working groups


The goal of the OMINEX project (Optimization of Monitoring for Internal Exposure), which is part of the 5th Framework Programme for Research and Technological Development (FPRTD) EURATOM (1998-2002), was to provide advice and guide the design and implementation of workplace monitoring programmes, adopting the ALARA (As Low As Reasonably Achievable) principle as regards internal radioexposure. European radiological protection institutes conducted this project over a two-year period. The first action of this European group was to carry out a survey of existing programmes in Europe, in order to be able to propose an international approach to the practical organization of radioprotection and the optimization of individual and collective monitoring.

The article by G. Etherington and al in 2003 [64 – Level of Evidence 4] provides an overview of the European OMINEX programme to optimize the monitoring of exposed workers. The authors describe the conditions for the creation of monitoring programmes for common radionuclides, the analytical methods used and the associated uncertainties. This article credibilises the recommendations of the ISO 20553 standard and the approach of this document. It provides no data, but the principles for monitoring implementation are presented for uranium, thorium, iodine and caesium.
5-1-6. | French working groups

1. NATIONAL GUIDE OF THE FRENCH NUCLEAR SAFETY AUTHORITY (ASN) [5 – 2008]

National guide: medical intervention following nuclear or radiobiological events.

“Publications for professionals: the national guide to medical intervention following nuclear or radiological events, co-written by a team of professionals, is a practical tool designed for healthcare players who may intervene following events involving radioactive substances.”

2. BIOTOX GUIDE OF THE FRENCH NATIONAL RESEARCH AND SAFETY INSTITUTE (INRS) [14 – 2007]

Biotoxicological guide for occupational health practitioners. Inventory of biological dosages available for monitoring subjects exposed to chemical products.

The “BIOTOX” database was constituted to guide occupational health practitioners conducting biological monitoring of exposure to chemical substances. It was developed after a bibliographic and scientific literature review, therefore drawing on updated knowledge of biomarkers for common toxic industrial products. The database takes the form of monographs for each industrial substance; these summarize the kinetic and metabolic data, practical information on sampling and analytical methods and the biological limits found in various matrices, in order to facilitate interpretation. This action was conducted by the French National Research and Safety Institute (INRS). The publication we used is dated 2007.

5-1-7. | Professional recommendations

1. MEDICAL DEONTOLOGY CODE [55]

This appears in the French Public Health Code under the numbers R.4127-1 to R.4127-112 (update of the 14th of December 2006)

The Medical Deontology Code prescribes the conditions for practicing medicine, in particular as regards professional confidentiality and the technical independence of doctors.

Occupational health practitioners are subject to the same obligations as other doctors. For this reason, the employment contract binding them to their employer must not contain clauses that could prevent the health practitioner from conducting his work in accordance with the code. This aspect of employment contracts is always checked by the Departmental Medical Councils.

2. HAS GOOD PRACTICE RECOMMENDATIONS (2009) ON OCCUPATIONAL HEALTH MEDICAL FILES

These recommendations are aimed at enhancing the quality of information in occupational health medical files (DMST: Dossier Médical en Santé au Travail) in order to facilitate the evaluation of cause-and-effect links between workers’ health status and their current or past activities and working conditions. Emphasis is placed on traceability of professional exposure, health data and information, proposals and opinions given to workers by their occupational health practitioner. The recommendations specifically mention the legal conservation period for medical files (50 years after the last radioexposure: Article 4454-9 of the Labor Code). The question of the method of communicating DMSTs is not covered.

5-2. | Search strategy

In addition to the documents mentioned above, the literature search was supplemented by a keyword search, using “AND” combinations of keywords on MEDLINE, for all publications since 2005.

The latest normative and international recommendations were published in 2006, as already mentioned, so no bibliographic keyword search was made prior to 2005.

This search was supplemented by the experts on the basis of specific, targeted searches for:

- references in articles identified by the experts,
- references in reports published internally by the experts or by other professionals,
- references in documents presented at specialized congresses,
- the results of surveys of practices concerning various cases of contamination experienced in NIs, documented and analysed cases (some of which have been the subject of scientific publications or have been presented orally at congresses).

The tables in Appendix 3 show the number of references identified and the number selected for each subject, according to the keywords used.

The exclusion criteria of the references were:

- date for articles in the targeted search: prior to 2005,
- place: exclusion of articles concerning exposures outside NIs,
- language: only articles in English or French were used,
- radionuclides: exclusion of articles concerning radionuclides not selected for the guide (see recommendation limits),
- exclusion of articles concerning expertise and without interest for practical application.

This search allowed six types of publications to be selected:

- analyses of cases with human data,
- analyses of experimental data,
- descriptive roundups and synthetic articles,
- methodical approaches and statistical studies,
- measurement methods,
- authors’ opinions.
<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>REFERENCES</th>
<th>LEVEL OF EVIDENCE</th>
</tr>
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<td>Objectives</td>
<td>22-23-58-90-91-120-125</td>
<td>3 4</td>
</tr>
<tr>
<td>Choice of model and parameters</td>
<td>18-25-56-60-137-152-159-165-173</td>
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<td>Alternative methods</td>
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</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>34 24 91</td>
</tr>
</tbody>
</table>

* References taken from normative and international recommendations, as well as those in international reports with a high level of evidence are not included in this list.
SECOND PART.

Case statement
INTRODUCTION.
1-1 | Definition and regulation

1-1-1 | REGULATORY SETTING

In 2003, several decrees retranscribed in 2007 into the French Labor Code and Public Health Code, specified a new regulatory framework for the medical-occupational monitoring of workers exposed to ionizing radiation:
- yearly exposure evaluations must be carried out and documented,
- annual dose limits must be defined and procedures must be followed in the event of excess exposure,
- Occupational Health Services (OHS) must, together with risk prevention services and expert units, ensure the monitoring of staff involved at nuclear installations (NIs).

- NI occupational health practitioners are responsible for internal doses assessment.
In the nuclear field, the tests prescribed in this context are performed by structures within operational companies (medical biology laboratories or OHS, in some cases).

In parallel, the mandatory multidisciplinary approach aimed at enhancing primary prevention and the traceability of occupational exposure cases has been asserted, as well as the patient’s right to be informed.

1-1-2 | HOW SHOULD INTERNAL EXPOSURE TO RADIONUCLIDES BE DEFINED?

Internal exposure to radionuclides is the regulatory term used to speak of internal contamination. This corresponds to the penetration (intake) within the human body of one or several radionuclides. This term was retained by analogy with that of external exposure, for which the irradiation stops as soon as the worker has left the workplace.
On the contrary, in the case of internal exposure, the irradiation continues for as long as the radionuclides have not been eliminated from the body, even after the worker’s withdrawal from the workplace.

The consequence of internal exposure can be evaluated by assessing the dose being delivered to the entire body (effective dose) over a given time period (hours, days, months, years) depending on the radionuclide’s elimination rate.
The calculation of the effective dose takes into account the time of retention within the body; hence, the name of “committed effective dose” (over time). As is regulatory for the worker, the calculation is made over a period of 50 years after exposure. This is an essential step in guiding the occupational health practitioner’s decisions.

1-2 | Demographic and qualitative data


Around 64,000 workers are concerned by NI internal exposure monitoring.
Such monitoring has involved tests falling into the following categories:

- Routine monitoring: 311,560 tests
  Number of anthroporadiometric tests: 197,901 tests
  Number of radio-toxicological analyses: 113,659 distributed thus:
  - 56,873 nasal sample analyses
  - 49,656 urine sample analyses
  - 7,130 faecal sample analyses

- Special monitoring: 10,473 tests

It is important to stress that the finding exceed the recording level in only 46 tests, i.e., in less than 1%.
The topic of these good practice recommendations, based on scientific knowledge and on feedback from professional practice is the medical-occupational monitoring of internal exposure to radionuclides in NI.

These recommendations are aimed at optimizing the prevention of internal exposure risks, as well as the medical follow-up of workers exposed to such risks by allowing:
– the professional practices of occupational health practitioners to be standardized,
– primary prevention to be enhanced, by helping to improve the workplace radiological cleanliness in coordination with the other persons involved in the prevention of occupational health hazards and by taking into account the feedback,
– to the activities intended to inform workers of the nature of such risks to be improved.

These meet a threefold goal:
1/ the improvement of the implementation of monitoring protocols suitable for the exposure risk,
2/ the specification of the method used for interpreting the monitoring data,
3/ the availability of elements for assessing the health risks associated with a dose.

These recommendations answer the following questions:
Regarding implementation – communication – traceability and filing (Topic A)
– Why should the dose be assessed and what level should be started from?
– How should it be done and by whom?
– What results must be conveyed? To whom? In what form?
– How should the results be logged and filed?

Regarding monitoring programmes (Topic B):
– What are the purposes, principles and categories of the monitoring programmes?
– What elements are needed for risk evaluation?
– What protocol should be implemented and how should its relevance be validated?
– How do social-economic elements affect the monitoring programme?

Regarding the assessment of the committed effective dose (Topic C):
– What default models and parameter values should be used?
– What method should be used for a prompt interpretation of the first test results?
– How can the incorporated activity and the committed effective dose be assessed and validated?
– What can be said of the uncertainty in the result of the dose estimate?
– What can be expected of dose calculation software?
– What are the alternatives to the use of the default model?

Regarding health risks and case management by the occupational health practitioner (Topic D)
– Starting from what committed effective dose should health risks be evaluated?
– How should these be evaluated?
– What answer should be given to workers regarding the estimated dose significance in terms of health?

These recommendations pertain to the medical-occupational health field of the NI nuclear sector, but they can serve as a basis for making recommendations covering a broader scope, encompassing the medical sector, research and non-nuclear industries. They are also limited partly owing to the specificity of French regulations on the matter.

RECOMMENDING THE CIRCUMSTANCES OF EXPOSURE
These recommendations are concerned with exposure by inhalation, which is the main route of exposure as far as workers are concerned.
They also address the issue of exposure consequent to contamination through a contaminated wound, which can cause a local dose at the entry site and a dose related to direct systemic transfer (passage into the bloodstream as per the “injection” model).
They do not address the issue of exposure cases consequent to the ingestion of contaminated products, which is the main mode of exposure throughout the population.

RECOMMENDING THE RADIONUCLIDES OF CONCERN, the recommendations are limited to the main radionuclides implicated in occupational exposure at NIs. These are:
1-6 | Population and health staff concerned

These recommendations concern all workers (around 64,000 – IRSN report of 2009) involved in a nuclear installation (NI) either civil or military (i.e., 126 NIs distributed over the French territory as on the 31st of December 2010 – source: Decision No.2011-DC-0204 of the Nuclear Safety Authority dated the 4th of January 2011) and subject to an internal radionuclide exposure risk.

The NIs concerned are essentially those of the following operators:
- AREVA,
- The French Atomic Energy and Alternative Energies Commission (CEA),
- The French electric company, Électricité de France (EDF),
- the French Directorate General of Armaments (DGA: Direction Générale de l’Armement) and the Defence sector.

They are intended for occupational health professionals practicing in the field concerned, i.e., around 450 occupational health practitioners and their teams (occupational health nursing staff). They may also address hospital doctors, first-aid workers, etc., expected to take charge of radiological accident victims within the framework of the Nuclear Risk in the Nuclear Radiological Biological Chemical (NRBC) plan.

1-7 | Recommendation plan

The recommendation plan, the issues addressed in reply to the questions asked (see Chapters 1-4) and the structuring of the guide were chosen at plenary meetings.

Four main topics were retained:
1/ Topic A | Assessment of the committed effective dose: Objectives – Implementation – Communication – Traceability and Filing
2/ Topic B | Monitoring programmes
3/ Topic C | Dose assessment based on the findings,
4/ Topic D | Health risk and management by the occupational health practitioner

For each sub-topic or issue, the following plan was used:
- A targeted excerpt from the regulatory or normative requirements and/or international recommendations,
- An analysis of the literature and data derived from professional practice,
- The opinion of the Working Group,
- The recommendations, as rated according to the level of evidence.

* name of the radionuclide, chemical form and absorption type in parentheses.
TO-
PIC
A.
**ASSESSMENT OF THE COMMITTED EFFECTIVE DOSE:**

**OBJECTIVES – IMPLEMENTATION – COMMUNICATION – TRACEABILITY AND FILING**

This chapter introduces the bases for internal dosimetry. It addresses the following issues, thereby helping to implement the monitoring of internal radionuclide exposure at NIs:

- Why should the dose be estimated?
- Starting from what level should the dose be estimated?
- Who is in charge?
- How should the dose to be estimated?
- What findings should be communicated? To whom? In what form?
- How should these be logged and filed?

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**A-1 | OBJECTIVES OF THE COMMITTED EFFECTIVE DOSE ASSESSMENT**

- Why should the dose be assessed?
- Starting from what level should the dose be assessed?

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**Q. A-1-1 | Why should the dose be assessed?**

**REGULATIONS**

**FRENCH PUBLIC HEALTH CODE IN FORCE ON 31/12/2010 [1-7]: ARTICLE L 1333-1**

“Any activities involving a risk of exposing people to ionizing radiation, herein below referred to as nuclear activities, either emanating from an artificial source, whether it be a substance or a device, etc., must fulfil the following principles:

1° No nuclear activity or intervention can be undertaken or exercised unless it is justified by the benefits that it can provide, in particular in terms of health, social, economic or scientific benefits, as compared to the risks inherent to the exposure to ionizing radiation, to which such activity is likely to subject the persons;

2° The exposure of persons to ionizing radiation resulting from any such activity or intervention must be maintained at the lowest level that is reasonably feasible, in view of the state of the techniques, of the economic and social factors and, possibly, of the medical goal pursued;

3° A person’s exposure to ionizing radiation resulting from any of these activities must not bring the sum of the doses received above the limits set forth by the regulations, except when the person is subjected to a medical treatment or included in biomedical research involving ionizing radiation.”

**LABOR CODE IN FORCE ON 31/12/2010 [1-1]**

[R 4451-1] “The rules for the prevention of risks concerning the health and safety of workers, including
independent workers and employers, exposed to ionizing radiation are set forth in compliance with the general principles for the protection of people against radiation as stated in Article L 1333-1 of the Public Health Code and with the requirements set forth by Article L 1333-10 of the same code.

\[L\ 4121-2\] “The employer shall implement the proceedings described in Article L. 4121-1 on the foundation of the following general prevention principles:
1° Avoid risks;
2° Evaluate any risks that cannot be avoided;
3° Fight the risks at the source;
4° Adapt work to man, in particular as far as workplace design and the choice of work equipment are concerned, as well as the work and production methods, in order in particular to limit monotonous work and sustained work-rates, and to reduce the effects of these on health;
5° Take into account the state of technical progress;
6° Replace what is hazardous by what is not, or by something less hazardous;
7° Draw up a prevention plan that integrates, within a consistent whole, the technique, the organization of work, the working conditions, social relations and the impact of environmental factors, especially the risks related to moral harassment, as defined in Article L. 1152-1;
8° Take steps towards collective protection by prioritizing these over individual protection endeavours;
9° Give appropriate instructions to the workers.”

\[R\ 4451-12\] “The sum of the effective doses received through external and internal exposure must not exceed 20 mSv over twelve consecutive months.”

\[R\ 4451-86\] “After any occurring internal or external exposure…, the occupational health practitioner shall establish a dosimetric record of this exposure, as well as one listing the effects thereof on each of the exposed workers. If necessary, he/she shall consult with the French Institute for Radiological Protection and Nuclear Safety.”

\[L\ 4121-2\] “The employer shall implement the proceedings described in Article L. 4121-1 on the foundation of the following general prevention principles:
1° Avoid risks;
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7° Draw up a prevention plan that integrates, within a consistent whole, the technique, the organization of work, the working conditions, social relations and the impact of environmental factors, especially the risks related to moral harassment, as defined in Article L. 1152-1;
8° Take steps towards collective protection by prioritizing these over individual protection endeavours;
9° Give appropriate instructions to the workers.”

\[R\ 4412-12\] “If the results of the risks evaluation reveal a risk for the health and safety of workers, the employer shall implement the following measures:
1° Prevention measures and means provided by Articles R. 4412-15 to R. 4412-22;
2° Checking of the collective protection installations and equipment as provided for in Sub-section 4;
3° Exposure control as provided for in Sub-section 5;
4° Measures in case of an accident, as provided for in Sub-section 6;
5° Workplace notice as provided for in Article R. 4412-39;
6° Medical follow-up and monitoring of the workers as provided for in Sub-section 8.”

\[CIRCULAR\ DGT/ASN\ NO.04\ OF\ THE\ 21ST\ OF\ APRIL\ 2010\ [1-5]\]
[Sheet 6 – 1-3] “… the occupational health practitioner shall also check for compliance with the exposure limits.”

**INTERNATIONAL STANDARDS AND RECOMMENDATIONS**

**ISO 20553 [3-1 ; 2006]**

“The purpose of monitoring, in general, is to verify and document that the worker is protected adequately against risks from radionuclide intakes and the protection complies with legal requirements.”

The obtained data is used “for dose assessment required for estimating risk and determining the need for any treatment, [and for] radiation-protection optimization process.”

**ICRP 60 [2-6 ; 1990] REPRODUCED IN ICRP 103 [2-17 ; 2007]**

The radiological protection system … is based on the following general principles:

(§203) “the principle of justification,
- the principle of optimisation of protection,
- the principle of application of dose limits,”

**ICRP 78 [2-13 ; 1998]**

(§10) “The principal objectives of individual monitoring for intakes of radionuclides are:
(i) to obtain an assessment of the committed effective dose and, where appropriate, the committed equivalent dose in significantly exposed tissues, so as to demonstrate compliance with managerial and regulatory requirements,
(ii) to contribute to the control of operation and the design of facilities, and
(iii) in the case of accidental exposure, to provide valuable information for the initiation and support of any appropriate health surveillance and treatment.”

**ICRP 103 [2-17 ; 2007]**

(§141) “For compliance with dose limits, the Commission continues to recommend that the committed dose is assigned to the year in which the intake occurred.”
The 2004 article by N. Blanchin and al. [22 – Level of Evidence 2] is a case study analysis based on human data bearing on the management, between 1996 and 2002, of approximately 1,500 situations of exposure to actinide oxides consecutive to an identified event (inhalation and wounds represented 88% and 12% of the exposure situations, respectively) with 23 different doses. The authors indicate the objectives that are the mainstay of a special monitoring programme (after an identified event):

- early implementation of treatment,
- decision as to the worker’s aptitude to continue or not with his/her activity in a restricted area,
- dose assessment in cases of significant intake.

“As Low As Reasonably Achievable”), to serve as a general framework for radiation protection. The three basic principles set forth, i.e., justification, optimization and limitation, refer item per item to the general principles of primary prevention stated in the French Labor Code:

- the principle of substitution whenever possible,
- the principle of introducing protection means at the workplace allowing the workers’ exposure risks to be reduced as much as possible,
- the principle of compliance with regulatory values.

The regulations set forth, as a first goal, the checking of compliance with the regulatory 20 mSv limit over 12 consecutive months. The ISO 20553 standard does not give any additional indications on the radiation protection objectives.

ICRP Publication 60, reproduced in Publication 103 and transposed into the French Public Health Code goes beyond the dose limits by proposing the optimization approach (formerly referred to as ALARA “As Low as Reasonably Achievable”) via the detection of low-level contamination cases (below recording level).

These objectives imply that the following actions should be taken:

- possible therapeutic management,
- evaluation of the person’s capacity to work in a radiological zone entailing possibly the decision to exclude such a person from working in a radiological zone during the year of the event, and to be re-evaluated periodically,
- provision of information to the workers,
- necessity of implementing the most suitable post-exposure monitoring.

Any actions and medical decisions taken must be justified and recorded in the worker’s medical file.
As from what level should a dose be recorded?

REGULATIONS
No reference is available, except for the regulatory limit values, including in particular the regulatory annual limit concerning exposure of the population in general, set at 1 mSv.

INTERNATIONAL STANDARDS AND RECOMMENDATIONS
ISO 20553 [3-1; 2006]
§(§) “The recording level is the level of dose, exposure or intake (specified by the employer or the regulatory authority) at or above which values of dose, exposure or intake received by workers are to be entered in their individual exposure records […] The recording level shall be set at a value corresponding (having regard to the length of the monitoring interval) to an annual dose no higher than 5 % of the annual dose limit.”

ICRP 78 [2-13; 1998]
§(Glossary) “Reference level are values of measured quantities above which some specified action or decision should be taken”. “They include:
- recording levels, above which a result should be recorded, lower values being ignored;
- investigation levels, above which the cause of the implication of the results should be examined;
- action levels, above which some remedial action should be considered.”

France did not take up this survey. The article lists the recording level (RL) values retained by the different countries. These values range from 0.0002 mSv to 2 mSv depending on the countries and the values may vary according to the radionuclide of interest.

CASE STUDY ANALYSIS BASED UPON HUMAN DATA
The 2005 article by N. Blanchin and al. already mentioned in A-1 [23 – Level of Evidence 2] is based on the 1 mSv recording level (RL).

The 2004 article by N. Blanchin and al. already mentioned in A-1 [22 – Level of Evidence 2] is based on the recording level (RL) used at the time, i.e., 1.66 mSv, to retain a committed effective dose.

The 2003 article by B. Le Guen and al. [120 - Level of Evidence 2] is a case study analysis based on human data. It describes the monitoring of the risk of exposure to alpha emitters of maintenance operators in an electric power plant in France; it presents the follow-up findings derived from individual analyses pertaining to 470 workers over year 2001 in the course of maintenance operations carried out during a generating unit stoppage event. The recording level used in this article is 1 mSv.

AUTHOR’S OPINION
The K. Henrichs’ 1998 article [90 - Level of Evidence 4] is an author’s opinion on the monitoring of workers exposed to a risk of internal contamination. It lists all of the aspects pertaining to the monitoring of exposures to be used for discussions within the

LITERATURE REVIEW

METHODICAL APPROACH
The K. Henrichs’ 2007 article [91 - Level of Evidence 4] presents a methodical approach for establishing a monitoring programme, based on the general principles found in the ISO 20553 standard. It specifies the purpose of a systematic individual monitoring programme, which is to guarantee the detection of any intake greater than 1 mSv (recording level).

The article by H. Doerfel in 2007 [58 – Level of Evidence 4] presents the methodical approach developed within the framework of the European IDEAS project, as well as an expert internal dosimetry software tool IDEAS (Internal Equivalent dose Assessment System). The author lists the general principles of routine monitoring, as a reminder, which are based on an initial evaluation of the risk of exposure at the workplace, in order to determine the nature and the frequency of the measurements. The criteria for such an evaluation of the risk of exposure are not detailed in the article. The implementation of routine monitoring from a potential exposure level of 1 mSv is proposed.

DESCRIPTIVE FINDINGS
The 2004 article by M. A. Lopez Ponte and al. [125 - Level of Evidence 4] presents descriptive findings that synthesize the answers to the EURADOS (European Radiation Dosimetry Group) questionnaire, including 71 complete answers originating from 26 countries on individual monitoring methods applied to detect internal exposure, which were sent out in 2002 to the different Member States.
It proposes to set as a goal a dose to be detected that is 10% that of the annual limit (2 mSv).

TO SUMMARIZE
To date, no reference threshold or level has been defined by the regulations. The scope of the [French] Labor Code remains quite broad by mentioning the need for an evaluation “after any internal exposure”. Article [R 4451-12] specifies that the doses retained are compared with the regulatory limit values over a period of 12 consecutive months.

The ISO 20553 standard and ICRP Publication 78 have defined reference levels referred to as recording level and investigation level, and even action level. They propose the use of the 1 mSv-per-year value as the recording level value.

ADDITIONAL INFORMATION
The 2004 article by M. A. Lopez Ponte and al. [125] shows that the recording levels retained by the various countries range from 0.0002 to 2 mSv, which values may vary depending on the radionuclide of interest. It is however noteworthy that France, which is the European Union country that is the most widely experienced in the field of individual monitoring of internal exposures (see the published feedback) due to its specificity regarding occupational medicine, did not answer the survey. In various recent French publications [23], [22], [120], the recording level retained is invariably 1 mSv.

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<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
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TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.
Prior to establishing the monitoring programmes discussed under headings B-2-2 and B-3-2, it is necessary to determine the level as from which a dose should be retained and recorded.
In the lack of any regulation-defined reference levels and in view of the international recommendations, guide values must be defined that are directly applicable in daily practice.

The WG retains a single reference level called the recording level (RL) expressed in dose units and sets its value at 1 mSv over 12 consecutive months.

The WG considers that it is necessary to launch further investigations, both on the workers (control bioassay measurements) and the workplace whenever it is suspected that intake may exceed the RL. Similarly, corrective actions should be considered in connection with radiation protection. Hence, the other reference levels (investigation and action levels) overlap and the WG only retains the notion of recording level.

The 1 mSv value is in agreement with that retained by ISO 20553 [3-1] standard and ICRP Publication No.78 [2-13], as well as with most of the professional practices published.
This value is also that chosen by the IRSN in the establishment of the annual assessment of exposure for workers exposed and corresponds to the annual exposure limit value for the public.
It is applicable to occupational exposure cases as a whole, as observed over 12 consecutive months, whether it be estimated in the course of the occasional treatment of isolated events (single incident) or upon yearly evaluations of internal exposure (combined incidents throughout the year).

Thus, the 1 mSv value is the guideline value retained as from which a committed effective dose must be estimated, retained and recorded. It is a precondition for the implementation of monitoring programmes (see Topic B).
Nevertheless, the WG stresses that, while it is possible in the case of certain radionuclides (gamma emitters for example) to detect very low doses (of the order of a microSv, or even less), it is hardly possible, particularly for alpha emitting radionuclides, to guarantee the detection of doses below 1 mSv.
Special case: a dose below the RL can be recorded by the occupational health practitioner if there is sufficient data available, using bioassay measurements that meet quality criteria (see Topic B-4) and when the measurement results obtained are all consistent (see Topic C-4).

For the estimates of the committed effective dose following a single exposure:
– equal to or greater than 1 mSv, the value of the dose must be recorded
– below 1 mSv, no dose value is to be recorded.

In the case of repeated exposures over a twelve consecutive month period, if the cumulated committed effective dose is equal to or greater than 1 mSv:
– the value of the dose must be recorded.

In all cases, all of the measurements and estimate results are saved in the medical file.

### R. 2 | As from what level should a dose be recorded? (Professionnal agreement)

Any dose above 1 mSv must be recorded for all internal exposures over twelve consecutive months.

This value, referred to as the recording level (RL), is the reference level that conditions the actions implemented within the framework of internal exposure monitoring by:
– taking the dose into account in the worker’s annual total cumulated dose,
– recording the dose in the IRSN's database SISERI (Information System for the monitoring of the professional Exposure to Ionizing Radiation).

For the estimates of the committed effective dose following a single exposure:
– equal to or greater than 1 mSv, the value of the dose must be recorded
– below 1 mSv, no dose value is to be recorded.

In the case of repeated exposures over a twelve consecutive month period, if the cumulated committed effective dose is equal to or greater than 1 mSv:
– the value of the dose must be recorded.

In all cases, all of the measurements and estimate results are saved in the medical file.

### A-2 | IMPLEMENTATION OF THE DOSE ASSESSMENT

**Q. A-2-1 | Who is in charge?**

**Who is in charge?**

**How should the dose be estimated?**

**REGULATIONS**

**LABOR CODE IN FORCE ON 31/12/2010 [1-1]**

(R 4451-64) “Internal exposure measurements or calculations … as provided for in Article R 4453-19 [newly codified as 4451-62] shall be carried out by one of the following organizations:
1° the French Institute for Radiological Protection and Nuclear Safety;
2° an occupational health service holder of the accreditation certificate;
3° an organization or a medical biology laboratory holder of an accreditation certificate and approved by the Nuclear Safety Authority.”

(R 4451-86) “After any occurring internal or external exposure …, the occupational health practitioner shall carry out a dosimetric assessment of this exposure and shall assesses the effects thereof on each exposed worker. If necessary, he/she shall consult with the French Institute for Radiological Protection and Nuclear Safety.”

**Decree of the 20th of December 2004, Article 4-I [1-3] “…The dosimetric body responsible for the internal dosimetry shall forward all individual bioassay measurements results to the occupational health practitioners who prescribed these measurements, so that he/she may determine the internal dose received by the worker if the conditions under which the exposure took place allow it…”**

**Decree 97-137 of the 13th of February 1997, Article 45-3 [1-6] non-abrogated “The occupational health practitioners of the institutions in which the nuclear installations are located shall ensure the evaluation of the internal exposure of the workers concerned by the provisions set forth in Articles 45-1 and 45-2. They shall send the results to the occupational health practitioners of external companies.”**

**ADDITIONAL INFORMATION**

Note that these provisions are related to the specificity of occupational health medicine in France. Thus, in many other European countries, these missions are rather carried out by expert radiation protection engineers.
In the particular case of activities subject to authorization in application of Article L. 1333-4 and when a knowledge of the exposure parameters allows a more precise estimate, other methods may be used provided that they have been approved by a decision of the Nuclear Safety Authority, officially recognised by the Health Minister after consulting with the French Institute for Radiological Protection and Nuclear Safety.

DECREE DATED 1ST SEPTEMBER 2003 [1-2]
The Decree of the 1st of September 2003 [1-2] defines the terms of calculation of the effective dose resulting from internal exposure to ionizing radiation via inhalation or ingestion.

Article 1 “… The committed dose associated with a wound leading to internal contamination shall be taken into account, when applicable, when estimating the effective dose.”

INTERNATIONAL RECOMMENDATIONS
ICRP 60 [2-6 ; 1990] RESTATE IN ICRP 103 [2-17 ; 2007]
(§89) “Assessment of dose from intakes of radionuclides falls into three stages:
(I) individual monitoring measurements,
(II) assessment of intake from the measurements, and
(III) assessment of dose from the intake.”

ICRP 78 [2-13 ; 1998]
The principles for the calculation of the intake and of the effective dose, based on the models proposed, are described in ICRP Publication 78.

ICRP 103 [2-17 ; 2007]
(§141) “For workers, the committed dose is normally evaluated over the 50-year period following the intake. The commitment period of 50 years is a rounded value considered by the Commission to be the working-life expectancy of a young person entering the workforce.”

Note | Literature references | Level of evidence
--- | --- | ---
3 | 2/6*-2/13* – 2/17* | 3*
THE INTAKE \((A_{\text{inh}})\) consecutive to the inhalation of the radionuclide \(j\) is expressed in Bq. It is evaluated based on the measurement results. The appendices to ICRP Publication 78 provide the retention or excretion function values over time \((t)\), following the intake of 1 Bq at time \(t_0\).

THE COMMITTED EFFECTIVE DOSE resulting from internal exposure \(E_{\text{internal}}\) is estimated based on the value retained for the intake. It is expressed in Sv.

The appendices to the Decree of the 1st of September 2003 [1-2] provide the coefficients for the committed effective dose per unit intake \((h(g)\text{ or DPUI})\) for the inhalation by an individual of age group \(g\) of a radionuclide \(j\), expressed in Sv per Bq.

In the case of systemic passage through healthy skin or a wound, the retention or excretion functions and the dose coefficients are provided in the ICRP publications and NCRP and IAEA reports (Topic C-3-3 – R 59).

\[
E = E_{\text{EXTERNAL}} + E_{\text{INTERNAL}}
\]

The occupational health practitioner shall check the compliance with the regulatory exposure limits for integrating the committed effective dose over the 12 consecutive month period.

The approach for assessing the committed effective dose involves three steps:
- Prescribing and carrying out measurements on the whole body, organs and/or biological samples within the framework of monitoring programs, depending on the material and the circumstances of exposure (Topic B),
- Evaluating the intake and the committed effective dose, taking into account any possible administered treatments (Topic C).

**R. 4 | How should the dose be assessed? (GRADE A)**

**THE INTAKE** \((A_{\text{inh}})\) consecutive to the inhalation of the radionuclide \(j\) is expressed in Bq. It is evaluated based on the measurement results. The appendices to ICRP Publication 78 provide the retention or excretion function values over time \((t)\), following the intake of 1 Bq at time \(t_0\).

**THE COMMITTED EFFECTIVE DOSE** resulting from internal exposure \(E_{\text{internal}}\) is estimated based on the value retained for the intake. It is expressed in Sv.

The appendices to the Decree of the 1st of September 2003 [1-2] provide the coefficients for the committed effective dose per unit intake \((h(g)\text{ or DPUI})\) for the inhalation by an individual of age group \(g\) of a radionuclide \(j\), expressed in Sv per Bq.

In the case of systemic passage through healthy skin or a wound, the retention or excretion functions and the dose coefficients are provided in the ICRP publications and NCRP and IAEA reports (Topic C-3-3 – R 59).

**A-3 | COMMUNICATION – DOSE TRACEABILITY AND FILING**

- What results should be communicated? To whom? In what form?
- How should the logging and filing be performed?

**REGULATIONS**

**LABOR CODE IN FORCE ON 31/12/2010 [1-1]**

(R 4451-68) “The dosimetry results … shall be communicated periodically to the French Institute for Radiological Protection and Nuclear Safety by: "1° the organizations mentioned in Article R.4453-21" [newly codified as 4451-64], “regarding reference dosimetry…””

(R 4451-63) “casein the event that one of the exposure limit values is exceeded… the occupational health practitioner and the employer shall immediately be informed thereof…” by the organizations in charge of the external and internal exposure measurements “The occupational health practitioner shall inform the employee concerned.”

(R 4451-99 and 4451-100) “The employer shall report” to the Nuclear Safety Authority “any significant event having caused or likely to be causing the limit value to be exceeded…”

**CIRCULAR DGT/ASN NO.04 OF THE 21ST OF APRIL 2010 [1-5]**

(Sheet N°5 – 2.1) “The occupational health practitioner, according to the elements gathered (i.e., the results of the measurements) shall calculate the dose received and forward the result to the IRSN (SISERI). He/she shall forward, at least once per year, the individual internal dosimetric results to the workers concerned.”

**Q. A-3-1 | What results should be communicated? To whom? In what form?**

This concerns:
- the exceeding of a regulatory individual annual dose limit
- the exceeding of a quarter of the regulatory individual annual dose limit.

This concerns:
- the exceeding of a regulatory individual annual dose limit
- the exceeding of a quarter of the regulatory individual annual dose limit.

**CIRCULAR DGT/ASN NO.04 OF THE 21ST OF APRIL 2010 [1-5]**

(Sheet N°5 – 2.1) “The occupational health practitioner, according to the elements gathered (i.e., the results of the measurements) shall calculate the dose received and forward the result to the IRSN (SISERI). He/she shall forward, at least once per year, the individual internal dosimetric results to the workers concerned.”
<table>
<thead>
<tr>
<th>LABOR CODE REFERENCE</th>
<th>WHO HAS ACCESS TO THE DATA?</th>
<th>WHAT DATA IS AVAILABLE?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Art R 4451-69</td>
<td>The prescribing occupational health practitioner, The worker's occupational health practitioner, The NI occupational health practitioner at the worker's site The worker and his/her dependents, The worker's family practitioner</td>
<td>All data available in nominative form without duration limit</td>
</tr>
<tr>
<td>Art R 4451-70</td>
<td>Radiation Protection Officer (RPO)</td>
<td>Operational dosimetry of the premises</td>
</tr>
<tr>
<td>Art R 4451-71</td>
<td>Radiation Protection Officer (RPO)</td>
<td>Effective doses received in nominative form Limited to the last 12 months</td>
</tr>
<tr>
<td>Art R 4451-73 Art R 4451-129</td>
<td>Labor Inspectorate agents Radiation protection inspectors Prevention service agents from the social security organizations</td>
<td>Overall data in nominative form</td>
</tr>
<tr>
<td>Art R 4451-70 Art R 4451-68</td>
<td>IRSN</td>
<td>Overall data in nominative form without duration limit + centralizing role (SISERI)</td>
</tr>
<tr>
<td>Art R 4451-99</td>
<td>ASN</td>
<td>Report of significant events</td>
</tr>
<tr>
<td>Art R 4451-70 Art R 4451-119</td>
<td>Employer Employer and CHSCT</td>
<td>Final statistical dosimetric report at least once per year</td>
</tr>
</tbody>
</table>

INTERNATIONAL RECOMMENDATIONS
ICRP 103 [2-17; 2007]
§141 “For compliance with dose limits, the Commission continues to recommend that the committed dose is assigned to the year in which the intake occurred.”

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2/17*</td>
<td>1*</td>
</tr>
</tbody>
</table>

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

Among all of the persons involved, some must mandatorily be informed about the committed effective dose:
- The employee, if possible, in writing.
- The NI Radiation Protection Officer at the employee's company.
- The IRSN, for an update of the SISERI file.

A special place must be made for the employee's employer and the NI manager, who do not have to know the dose for the 12 consecutive months (including the committed effective dose), but who must be warned if any dose should exceed a quarter of the annual limit values (the more so if the said dose is exceeded), in order for them to be able to make their report to the ASN.
### Professional Agreement

**After an event calling for dose estimation,** the result shall be communicated by the occupational health practitioner to the radiation protection officers at NI and at the worker’s company. See Appendix 6 to the case statement.

The occupational health practitioner shall indicate to the employer and to the NI manager, the dose level over 12 consecutive months as:
- less than a quarter of the limit value,
- greater than a quarter of the limit value,
- greater than the limit value,
so that they can make their mandatory report to the Nuclear Safety Authority. See Appendix 6 to the case statement.

### Regulations

Any committed effective dose greater than the Recording Level shall be communicated by the occupational health practitioner to the IRSN to be integrated to the 12-consecutive-month dose and to the worker’s life dose in the SISERI base (Information system for the monitoring of the exposure to ionizing radiation). See Appendix 6 to the case statement.

Although the effective dose is committed over a 50-year period, it is recorded and added to the effective dose for the month (single exposure) or the current year (repeated exposure) when the event took place. The occupational health practitioner shall ensure compliance with regulatory exposure limits for the integration of the committed effective dose with the 12-consecutive-month dose.

After an event calling for dose estimation, the occupational health practitioner shall inform the worker concerned of the result. In addition, a document written and signed by the occupational health practitioner certifying the estimated dose must be handed to the worker whose medical monitoring he/she is responsible for. See Appendix 6 to the case statement.

It is advisable for the result to be communicated to the concerned worker during a visit, so that the occupational health practitioner can answer any questions that the worker may have.

### Questions

**Q. A-3-2 | How should traceability and filing be performed?**

**Regulations**

**Labor Code in Force on 31/12/2010 [1-1]**

(R 4412-55) “The medical file shall be saved for at least fifty years after the end of the exposure period, under the conditions provided for in Article D. 4624-46 of this code…”

(R 4451-88) “The occupational health practitioner shall prepare and keep, for each exposed worker, an individual file containing:

1° A copy of the exposure sheet, as provided for by Article R. 4451-57;

2° The dates and results of the dosimetric monitoring of the individual exposure to ionizing radiation and the effective doses received, as well as the dates of the abnormal exposure events and the doses received in the course of such exposures;

3° The dates and results of medical laboratory tests obtained in application of Article R. 4451-84.”

**Circular DGT/ASN No.04 of the 21st of April 2010 [1-5]**

(Sheet N°6 – 2.1.2) “In order to ensure the traceability of the exposures, it is important for the number of medical files be limited. The medical file kept by the occupational health practitioner at the occupational health service of the external company must contain all of the “special” files and, more particularly, the NI ones related to the different occupational exposures of the worker.”

**International Standards and Recommendations**

**ISO 27048 [3-2; Publication 2011]**

“Sufficient records shall be kept of the details of all assessments so that the exact conditions of assessment may be reproduced in the future.”

**Professional Recommendations**

**Code of Medical Ethics [55]**

[Title 2 Article 45] “Regardless of the medical follow-up file provided for by law, the doctor must keep for each patient a personal observation sheet; this sheet is confidential and shall include the updated elements needed to make diagnostic and therapeutic decisions.

In all cases, these documents shall be kept under the responsibility of the doctor. Any medical doctor must, upon request by the patient, or with the latter’s consent, forward the data and documents useful for on-going patient care to the doctors participating in the case management, or to those whom he/she intends to confer with.”
NATIONAL AUTHORITY FOR HEALTH REFERENCE

Medical file in occupational health: Tables 3, 4 and 5
– Nature of the information concerning the work and the professional activities to be related in the Medical File of Occupational Health
– Nature of the information collected during the medical tests to be related in the Medical File of Occupational Health

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The regulations do not specify the items to be saved in the medical file, except for the measurement results and the assessed dose.

The WG recommends, with the purpose of standardization, the use of template traceability sheets. See Appendix 5 of the case statement.

<table>
<thead>
<tr>
<th>R. 6</th>
<th>How should traceability logging and filing be carried out? (Professionnal agreement)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The worker’s individual medical file, saved for at least 50 years after the end of the exposure event, must contain:</td>
<td></td>
</tr>
<tr>
<td>– all of the dated bioassay measurements results,</td>
<td></td>
</tr>
<tr>
<td>– the non-execution or non-compliance (see compliance criteria R28 to 32) of any measurement prescribed by the occupational health practitioner within the framework of a monitoring program must be logged,</td>
<td></td>
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<tr>
<td>– the traceability sheet in case of a dose assessment.</td>
<td></td>
</tr>
<tr>
<td>The traceability sheet shall include:</td>
<td></td>
</tr>
<tr>
<td>– the identity of the occupational health practitioner authorized to manage the dose estimate,</td>
<td></td>
</tr>
<tr>
<td>– the personal data of the expert possibly sought,</td>
<td></td>
</tr>
<tr>
<td>– the prescribed measurements,</td>
<td></td>
</tr>
<tr>
<td>– and all of the results, with an indication of those taken into account for the calculation,</td>
<td></td>
</tr>
<tr>
<td>– the treatment administered and its taking into account for dose assessment,</td>
<td></td>
</tr>
<tr>
<td>– the hypotheses retained for dose assessment (time and route of intake, physical-chemical, parameters, etc.),</td>
<td></td>
</tr>
<tr>
<td>– and the model retained (ICRP Publication 78, other, etc.).</td>
<td></td>
</tr>
<tr>
<td>This traceability sheet shall be forwarded to the occupational health practitioner if it is different from the NI practitioner’s sheet to be archived in the concerned worker’s medical file.</td>
<td></td>
</tr>
</tbody>
</table>
.FC
This chapter concerns the setting up of the monitoring programmes for internal exposure under various situations, whether within the framework of routine monitoring or following-up on a particular event.

The main issues that this chapter must address to guide the NI occupational health practitioner in his/her daily practice are as follows:

Regarding the purposes and implementation methods:
– What are the purposes of a monitoring programme?
– What are the principles for implementing an individual monitoring programme?
– What categories of monitoring programmes are distinguishable?

Regarding routine monitoring:
– What elements are necessary to carry out an analysis of the risk of exposure at the workplace?
– How should the risk of exposure be weighted?
– And starting from what level should a monitoring protocol be implemented?
– What protocol should be implemented?

– Under what criteria should the programme relevance be validated?

Regarding special monitoring:
– What elements are necessary to carry out an analysis of the event?
– How should the event-related risk of exposure be assessed (initial rating)? What are the relevant exposure indicators and how should the results thereof be interpreted?
– What protocol (type of measurements and frequency) and follow-up should be implemented?
– Under what criteria should the programme relevance be validated?

Regarding bioassay measurements:
– How should one particular measurement be chosen among those available?
– What are the importance and difficulties pertaining to the interpretation of laboratory measurements?
– What measurements are relevant in terms of the radionuclide concerned?

How do social-economic issues affect the monitoring programme?

B-1 | PURPOSES AND IMPLEMENTATION METHODS

– What are the purposes of a monitoring programme?
– What are the principles for implementing an individual monitoring programme?
– What categories of monitoring programmes are distinguishable?

REGULATIONS
LABOR CODE IN FORCE ON 31/12/2010 [1-1]
(R 4451-30) The analysis shall be based on the "measurements of the concentration of air activity and of surface contamination with an indication of the characteristics of the radioactive materials found", R 4451-62 "These shall be validated by the Radiation Protection Officer."
"...When there is internal exposure, [reference]"
dosimetric monitoring shall be provided by in vivo or in vivo measurements…”

CIRCULAR DGT/ASN NO.04 OF THE 21ST OF APRIL 2010 [1-5]
“As with any other occupational risk, the risk associated with ionizing radiation must be assessed by the employer beforehand…
…carried out based on “normal” work situations…
…more particularly, based on a workplace analysis, this allows the following:
…to define the type and terms of the radiological follow-up.”

INTERNATIONAL STANDARDS AND RECOMMENDATIONS
ISO 20553 [3-1; 2006]
OBJECTIVES
(§11.1.1) “the strategy shall set out the purpose and frequency of each type of measurement and the way the results are used in assessment of the dose received.”
(§5.7.8) “The purpose of monitoring, in general, is to verify and document that the 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 programme, which starts with an assessment to identify work situations in which there is a risk of radionuclide intake by 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 programme should be made in the light of such a risk assessment.”

WORKPLACE MONITORING
(§7-2) “Surface contamination is not directly related to individual exposure but can indicate increased risk of intake.”
(§5) “Workplace monitoring, which includes collective monitoring, provides exposure assessments for a group of workers assuming identical working conditions i.e. risks of intake as well as all factors influencing the resulting doses. It is mainly used in cases where individual monitoring is not appropriate and it can also be needed in those cases where individual monitoring is not sufficiently sensitive.”

ROUTINE MONITORING
(§7) “Routine monitoring programmes shall be established including suitable workplace monitoring and individual monitoring”

SPECIAL MONITORING
(§8-2) “Special monitoring programmes refer to measurements made when intake is suspected following an event. Special workplace monitoring is based on the same principles as for routine workplace monitoring and the same requirements shall be fulfilled”

ICRP 78 [2-13; 1998]
(§9) “The term monitoring is taken to mean both measurement and interpretation of measurement results.”

MONITORING OF WORK AIR ENVIRONMENTS
(§16) “The results of monitoring of the workplace may also indicate a need for a temporary programme of special individual monitoring aimed at identifying any need for a routine programme of workplace monitoring.”
(§76) “Static air samplers (SAS) are commonly used to monitor workplace conditions, but can underestimate concentrations in air in the breathing zone of a worker, typically by a factor of up to about 10”

ROUTINE MONITORING
(§11) “Routine monitoring would only be required in conditions of essentially continuous risk of contamination of the workplace as a result of normal operations… controlled areas… in which there are grounds for expecting significant intakes.”
(§86) “One method of confirming that working conditions are satisfactory is to carry out occasional individual monitoring. Such measurements can be interpreted only qualitatively, but unexpected findings would give grounds for further investigation.”

LITERATURE REVIEW
Several publications confirm the importance of implementing individual monitoring in addition to workplace monitoring, depending on the work situations and the radionuclides involved.

CASE STUDY ANALYSIS BASED ON HUMAN DATA
The 2005 article by N. Blanchin and al. already quoted in A-1 [23 – Level of Evidence 2] reveals:
– The importance of faecal analyses, as compared to urine analysis, for exposure to actinide oxides, allowing low intake detection (below 1 mSv),
– The rationale for individual monitoring in this type of work situation, which allows the detection of low-level contamination cases, most often…
related to direct ingestion of non-inhalable particles (particle size greater than 10 micrometers),
– The contribution to the improvement of “radiological cleanness of facilities”, as evidenced every year by the decrease in the percentage of positive results.

**Diagram No. 1. Complementarity of Workplace Monitoring and Individual Monitoring.**

Tiré de l’article de N. Blanchin and al. en 2005 [23].
The 2003 article by B. Le Guen and al. already quoted in A-1 [120 – Level of Evidence 2] differentiates 2 levels of monitoring:

– collective, through monitoring the ambient air at work
– individual, whenever the work situation can potentially lead to doses higher than 1 mSv / 12 months

The authors emphasize that collective monitoring results defining the monitoring programmes are validated by those from individual measurements performed on workers exposed to a dose potentially greater than 1 mSv / 12 month. This validates the fact that the monitoring of workers not directly exposed is not necessary.

The 1998 article by B. Gibert and al. [74 – Level of Evidence 2] is an analysis of a case study based on human data bearing on 23 situations of interhuman data providing feedback on the systemsatic monitoring for internal exposure in 5,000 employees exposed to uranium between 1964 and 1989 on several French sites producing uranium fuel.

During this period, 4,344 workers not belonging to the nuclear industry were subjected to individual monitoring. There is a need for the monitoring programmes to supplement the information from workplace monitoring. The intent of the article is therefore based on individual bioassay measurements, was 6,672, falling into the following radioisotope-related groups:

– 1,375 liquid scintillation counting analyses for tritium
– 873 alpha urine sample measurements for uranium
– 159 alpha bioassay measurements for americium-241
– 2,383 alpha bioassay measurements for plutonium-238
– 1,875 alpha bioassay measurements for plutonium-239

This article highlights the importance of individual monitoring to supplement the information from workplace monitoring. The intention of the article being the presentation of the IT management of the monitoring results, few precisions are provided regarding the monitoring programmes set up.

The 2008 article by BA. Ulsh and al. [169 – Level of Evidence 3] is a case study analysis based on human data carried out on a dozen workers, bearing on post-event dosimetric reconstitution of the internal dose related to the exposure to thorium during several special manufacturing operations involving thorium at a metal production plant in the sixties. The monitoring of workers (barely twelve) was then based on air and surface measurements supplemented with additional urine analyses, for which the time intervals are unknown. Given the lack of any positive bioassay measurement result (with no indication, however, of the technique used or of the detection limit), the dosimetric estimate made by the National Institute for Occupational Safety and Health (NIOSH), is based solely on air measurements.

**DESCRIPTIVE REVIEW ANALYSIS OF INDIVIDUAL MONITORING**

The 2007 article by L. Bertelli and al. [11 – Level of Evidence 2] presents a descriptive review analysis of individual monitoring involving approximately 1,800 workers at the Los Alamos (USA) site in 2005. The total number of individual measurements, including special and routine monitoring measurements, was 6,672, falling into the following radioisotope-related groups:

– 1,375 liquid scintillation counting analyses for tritium
– 873 alpha urine sample measurements for uranium
– 159 alpha bioassay measurements for americium-241
– 2,383 alpha bioassay measurements for plutonium-238
– 1,875 alpha bioassay measurements for plutonium-239

This article highlights the importance of individual monitoring to supplement the information from workplace monitoring. The intent of the article being the presentation of the IT management of the monitoring results, few precisions are provided regarding the monitoring programmes set up.

The 1998 article by C. Challeton de Vathaire and al. [40 – Level of Evidence 4] presents a descriptive appraisal of individual internal exposure monitoring in French workers exposed to radionuclides from February through August 1997.

During this period, 4,344 workers not belonging to the nuclear industry were subjected to individual internal exposure monitoring. There is a review of the main analysis techniques, primarily in vivo measurement and urine analysis, as well as of the usual time intervals between monitoring operations according to the type of radionuclide of
interest. The article also indicates the percentage of results exceeding the detection limit per radionuclide: 10.7%, 3.4%, 3%, 2.4%, for I-131, S-35, H-3, I-125, respectively. These results corroborate the importance, for employees, of individual monitoring, whose very high sensitivity – no figures provided – (intake detection beyond incident-related situations detected by radiation protection) allows the radiological cleanness of the workplaces to be optimized.

The 1997 article by W. Blommaert and al. [25 – Level of Evidence 4] presents a descriptive appraisal of individual monitoring for internal exposure of employees (number of employees and study period not indicated) exposed to the risk of internal contamination at a Belgian nuclear waste storage and renewed containment site. The main radionuclides to which the employees were exposed are: plutonium – americium – uranium – caesium – strontium.

The article highlights the complementarity of air monitoring at the workplace and individual urine analysis and, in the case of alpha emitters (particularly Pu – Am), faeces. Because of the sensitivity of the measurement (alpha detection limit of faecal measurements around 1 mBq) the authors conclude that it is important for routine individual monitoring to supplement radiological monitoring at the workplace, while drawing attention to the risk of triggering excessive reactions on the part of both the employers and the employees when faced with very low-level contamination screening (no dose retained).

**AUTHOR’S OPINION**

K. Henrichs’ 1998 article already quoted in A-1 [90 – Level of Evidence 4] recommends, in order to comply with the 2 mSv dose set value that the monitoring programme measurements provide for detecting a 0.6 mSv value. The author points out that for certain radionuclides (alpha emitters) the sensitivity of the analysis techniques does not allow this detection level to be attained. Individual monitoring is therefore supplemented by air monitoring closest to the workplace (PAS).

Q. What are the purposes of a monitoring programme and the types of monitoring to be defined?

**TO SUMMARIZE**

The regulations and the normative and international recommendations differentiate between workplace monitoring and individual monitoring. They emphasize the complementarity of both without however explaining the same on an operational level.

The international standard and recommendations emphasize the non-negligible risk of under-estimating (by a factor of 10) the intake through a monitoring procedure based solely on the air concentration values of the workplace. They stress the importance of controlling workplace data by occasional monitoring.

**ADDITIONAL INFORMATION**

All of the literature reviewed confirms the necessity, depending on the case, of supplementing workplace monitoring by individual monitoring. Only a few authors [23] [120] [74] [25] [90] expand on the relationship between the two levels of monitoring and, more particularly, the need for collecting workplace monitoring data in order to define individual monitoring.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
</table>

**TO CONCLUDE**

These arguments reinforce the Working Group’s position:
– a monitoring programme cannot be based solely on workplace monitoring,
– it must be supplemented by suitable individual monitoring, in order to meet the monitoring objectives, as defined under Topic A.
Three types of monitoring are distinguishable, each fulfilling a specific purpose in view of the objectives defined:

- **collectively-oriented monitoring** through workplace monitoring (radiation protection means),
- **individually-oriented monitoring** based on individual measurements,
- and **collectively-oriented individual monitoring**, which is based on the principle that the individual measurements serve to evaluate the exposure of the worker for whom a measurement has been prescribed, but also that of the other workers performing under the same conditions of exposure. This principle of collectively-oriented individual monitoring can be enhanced by staggering the measurements throughout the year for the workers monitored, thereby enabling each in turn to serve as an “exposure indicator” for the others.

These three types of monitoring are complementary and are often gathered within a single monitoring programme.

**TO SUMMARIZE**
As shown further into this chapter, the regulations and the normative and international recommendations provide some indications on the measurements (nature and frequency) to be carried out for the main radionuclides as a dosimetric evaluation to meet the requirement of “dosimetric monitoring and compliance with the regulatory limit values”.

However, these do not define the operational implementation methods of a monitoring programme, nor do they answer the question: “At what point should an individual monitoring protocol be implemented?”

**ADDITIONAL INFORMATION**
Some elements to address this question can be found in a few literature references, but mostly they are provided through experience feedback on professional practice, sometimes shared within a Working Group though seldom published (see further into this chapter for a more thorough analysis).

**TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.**
The first stage in any medical monitoring programme is to evaluate the risk of exposure at the workplace according to the objective previously set forth, that is, to:

1. determine whether or not individual monitoring is justified,
2. define the nature thereof.

This justifies the special recommendations set forth in the two chapters concerning specifically the “weighting of risk” for routine monitoring (Topics B-2-1 and B-2-2) and the “initial event rating” for special monitoring (Topics B-3-1 and B-3-2).

It is worth stressing the importance of this first stage, which in a significant percentage of the cases (so-called negligible risk situations) allows hard to justify and sometimes costly constraints set upon the workers at the risk of discrediting the other monitoring elements, to be dispensed with.

The next stage shall be, depending on the level evaluated during the first stage, to set up a medical monitoring protocol: type and frequency of the measurements, selection criteria between several techniques when several are available, conditions for implementing the measurements and workers concerned.

Lastly, an essential stage in all monitoring programmes consists in taking into account the feedback, enabling:

- on one hand, its evaluation in terms of relevance and efficiency,
- on the other hand, to assess the level of socioeconomic acceptance (see Topic B-5).

This evaluation is especially essential for programmes where additional individual monitoring is not implemented, in so-called “negligible risk work situations”.

**Q. What are the purposes of a monitoring programme? (GRADE A)**

**Q. What are the principles for implementing an individual monitoring programme?**
The setting up of any monitoring programme is based on:
1. regulatory and normative references and the scientific recommendations allowing the objectives of the monitoring programme to be explained,
2. knowledge of the items for the evaluation of exposure risk (stage 1),
3. evaluation of the potential risk following the analysis of the danger and exposure (stage 2),
4. setting up of the monitoring protocol depending on the laboratory measurement techniques that are available according to the radionuclide concerned, taking into account their detection limit (sensitivity) and specificity, as well as the time needed to obtain the results, while also taking into account the social-economic acceptance of the monitoring procedures (stage 3).
5. validation of the programme’s relevance and consistency (stage 4).

It is necessary to differentiate:
− term programme, which applies to the overall approach, starting from risk analysis to validation of the monitoring programme defined,
− protocol which applies more particularly to the prescription falling under medical occupational health responsibility.

A monitoring protocol must define:
− the nature of the measurement or measurements,
− the measurement schedule (immediate and/or distant further measurement)
− the conditions for the implementation of these (e.g., excluding or not excluding a zone at risk for contamination, etc.),
− workers directly concerned and those likely to be implicated after the survey.

Grounds. As defined, this programme cannot be used to carry out any dosimetric evaluations.

− Workplace monitoring programme: special routine monitoring programme pertaining only to a workplace particularly at risk.

INTERNATIONAL STANDARDS AND RECOMMENDATIONS

CATEGORIES OF MONITORING PROGRAMMES
− Routine monitoring programme: collective or individual systematic monitoring, for which the periodicity of the measurements complies with the monitoring intervals [3-1 (Tables 3-4-5)]
− Special monitoring programme: individual monitoring implemented following an incident or following a positive result during routine monitoring.
− Control monitoring programme: individual or collective (sampling) monitoring. This programme can be used, for example, to check whether a decision to not to set up any routine monitoring has good

TO SUMMARIZE
Standard ISO 20553 and ICRP Publication 78 adopt 4 categories of monitoring programmes: routine, special, control and workplace monitoring.

IN CONCLUSION, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.
In order to take into account the history of the monitoring programme nomenclature in the companies concerned and especially because the distinction between routine, control and workplace monitoring unnecessarily complicates the matter (since the practical procedures for these NI protocols are identical), the WG has decided to organize the presentation so as to retain only two categories of monitoring programmes:
− routine monitoring, which encompasses systematic, workplace and control monitoring programmes.

Its description and further recommendations are discussed under Topic B-2.
− special monitoring, which is triggered following an event or the disclosure of a positive measurement result during routine monitoring. Its description and further recommendations are discussed under Topic B-3.
Two categories of monitoring programmes are distinguishable according to the circumstances under which they are implemented:

1. **routine monitoring programme** which concerns the monitoring of the ordinary exposures at various workplaces.
   
   Diagram No.2 (R10) formalizes the approach for establishing a routine monitoring programme.

2. the **special monitoring programme**, which is implemented in two situations:
   - either following a documented event,
   - or following the discovery of a positive sample during the routine monitoring programme.
   
   Diagram No.4 (R16) formalizes the approach for establishing a special monitoring programme.

**SPECIAL CASES OF ROUTINE MONITORING**

Occasionally, a **control** monitoring programme can enable the evaluation of the level of exposure periodically, in situations where the risks are assessed to be negligible (R 13). Such evaluation validates and justifies not implementing the routine monitoring programme, or a lack thereof.

The monitoring protocol is based on the same measurements as those prescribed for routine monitoring.

**Worksite monitoring** is a special case of the routine monitoring that is implemented when the worksite is of a limited duration and when systematic monitoring cannot be efficiently implemented. In fact, the monitoring intervals are generally shorter than those for routine monitoring, since they are dependent upon the worksite duration.

The advantage lies in being able to adapt the monitoring programme to the duration of the worksite and to take into account the particularities of the exposure.

The principles stated for routine monitoring apply to worksite monitoring.

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**B-2 | ROUTINE MONITORING**

This chapter introduces the operational bases (methods and means) for setting up routine monitoring protocols to address the following issues:

- What are the elements needed to carry out the analysis of exposure risk at the workplace? **Stage 1**
- How should the exposure risk be weighted? And starting from what level should individual monitoring be implemented? **Stage 2**
- What protocol should be implemented? **Stage 3**
- Based upon what criteria should the relevance of the programme be validated? **Stage 4**

**B-2-1 | Approach for implementing a routine monitoring programme**

The logical diagram below is a synthesis of the stages whose content is discussed under the following topics.

For understanding purposes, it is inserted at the beginning of the chapter.

**R. 10 | What approach should be followed to implement a routine monitoring programme? (Professional agreement)**

**DIAGRAM N°2. APPROACH TO ESTABLISH A ROUTINE MONITORING PROGRAM.**
Q. What are the elements necessary to carry out a risk analysis at the workplace?

**REGULATION**

**LABOR CODE IN FORCE ON 31/12/2010 [1-1]**

(R 4121-1) “The employer shall transcribe and update in a single document the findings from the workers’ health and safety risk analysis carried out in application of Article L.4121-3. This evaluation shall include an inventory of the risks identified in each work unit of the company or institution, including those related to thermal environments.”

(R 4451-30) The analysis shall be based on “measurements of the air activity concentration and of the surface contamination, indicating the characteristics of the radioactive materials found”. (R 4451-62) “These shall be validated by the Radiation Safety Officer.”

(R 4451-57) “The employer shall establish an exposure sheet for each worker, containing the following information:

1° The nature of the work performed;

2° The characteristics of the emitting sources to which the worker is exposed;

3° The nature of the ionizing radiation;

4° The periods of exposure;

5° The other risks or nuisances with physical, chemical, biological or organizational causes at the workplace.”

**CIRCULAR DGT/ASN NO.04 OF THE 21ST OF APRIL 2010 [1-5]**

“As with any other professional risk, the risk related to ionizing radiation must be assessed by the employer beforehand…

…carried out based on “normal” work situations…

…it shall more particularly, based on a workplace analysis, enable:

… the type and terms of the radiological follow-up to be defined.”

**INTERNATIONAL STANDARDS AND RECOMMENDATIONS**

**ISO 20553 [3-1; 2006]**

($§7-2) “Surface contamination is not directly related to individual exposure but can indicate increased risk of intake.”

**LITERATURE REVIEW**

**CASE STUDY ANALYSIS BASED ON HUMAN DATA**

The 2005 article by N. Blanchin and al., already quoted in A-1 [23 – Level of Evidence 2] presents the elements retained to carry out an exposure risk analysis at the workplace, thereby allowing a systematic monitoring protocol to be defined:

– the presence or not of radionuclides apt to promote contamination,

– the activity handled,

– the work conditions and the nature of collective protections developed,

– the frequency of events warranting the drafting of a radiological data sheet,

– the time spent at the workplace.

The 2003 article by B. Le Guen and al., already quoted in A-1 [120 – Level of Evidence 2] defines the criteria for triggering the control monitoring of an actinide exposure risk:

– either by surface / air contamination detection,

– or by internal gamma contamination detection,

– or by positive nasal mucus sample analysis.

The 1998 article by B. Gibert and al., already quoted in B-1 [74 – Level of Evidence 2] shows the importance of characterizing material physicochemical parameters at the various workplaces, so as to define appropriate individual monitoring, as well as setting up the parameters for the PAS (personal air sampler) operational values that must trigger additional individual measurements (control measurements).

The 1989 article by J. Chalabreysse and al., already quoted in B-1 [36 – Level of Evidence 2] highlights certain points:

– the need to carry out measurements that are suitable for the chemical form of the material and for the type of absorption (fast, moderate or slow),

– the significant variability of the retention and excretion functions, depending on physicochemical parameters,

– the existence of mixed chemical forms, thereby explaining “atypical” behaviours as compared to ICRP reference models.

This article concludes that it is necessary to conduct specific studies at the workplace to develop specific biokinetic models.

**DESCRIPTIVE REVIEW ANALYSIS OF INDIVIDUAL MONITORING**

The 2007 article by T. Labarta and al. [113 - Level of Evidence 4] is a descriptive review analysis of individual monitoring, bearing on systematic monitoring of internal exposures of workers employed at the
The regulations and the international normative recommendations provide only scant indications regarding the elements that need to be collected at the workplace, in order to evaluate the potential exposure risks.

**ADDITIONAL INFORMATION**

Published professional practices [23] [120] [74] [113] explain much more systematically this point, the basic principles of which are recalled in publication [90].

The 1997 article by W. Blommaert and al. already quoted in B-1 [25 – Level of Evidence 4] emphasizes the importance of having the most precise knowledge possible of the isotopic composition and chemical form of the contaminating mixture, which presents some difficulty in facilities that are being dismantled, as well as in terms of the treatment of wastes derived from various installations.

**AUTHOR'S OPINION**

K. Henrichs' 1998 article, already quoted in A-1 [90 – Level of Evidence 4] lists the data allowing a monitoring programme to be implemented:

- identification of workplaces at risk,
- inventory of the radionuclides present,
- physicochemical characterization,
- measurement methods available,
- contamination risk assessment: probability and importance.

**TO SUMMARIZE**

The experience from professional practices shared within the WG reveals the difficulty in obtaining the data related to workplace exposure under some circumstances.

It enables the basis for the feasibility of obtaining the data to be validated. Hence, the recommended data is that which is the easiest to obtain without any special investigation, whereas the supplementary data is that which requires thorough investigation.

The WG draws attention to the fact that the monitoring programme for workers at their workplace and the protection means to be implemented must be all the more binding if the characterisation data is partial or lacking.

---

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>3/1* – 23-25-36-74-90-113-120</td>
<td>1* 4 3</td>
</tr>
</tbody>
</table>

**IN CONCLUSION, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.**

The experience from professional practices shared within the WG reveals the difficulty in obtaining the data related to workplace exposure under some circumstances.

It enables the basis for the feasibility of obtaining the data to be validated. Hence, the recommended data is that which is the easiest to obtain without any special investigation, whereas the supplementary data is that which requires thorough investigation.

The WG draws attention to the fact that the monitoring programme for workers at their workplace and the protection means to be implemented must be all the more binding if the characterisation data is partial or lacking.
The WG has summarized all of the elements that must be gathered at the workplace for each chemical form of every radioisotope in the form of a workplace worksheet (see R12), in order to:
1. evaluate the risk of exposure (weighting of the risk) (see R13),
2. define the nature and the frequency of the measurements to be prescribed for exposed workers (see R14).

This worksheet contains the information on the contaminating material and on the workplace characteristics. In the event of a lack of any information and whenever relevant, a default value shall be used.

### PRODUCT INFORMATION

<table>
<thead>
<tr>
<th>NATURE OF THE DATA</th>
<th>SOURCE</th>
<th>COLLECTION</th>
<th>DEFAULT VALUE *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radionuclides or isotope mixture</td>
<td>RP</td>
<td>Recommended</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Physical form (liquid – solid – gas)</td>
<td>RP</td>
<td>Recommended</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Chemical form (oxide, nitrate, etc.)</td>
<td>RP</td>
<td>Supplementary</td>
<td>Not applicable</td>
</tr>
<tr>
<td>(AMAD)</td>
<td>RP</td>
<td>Supplementary</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

### WORKPLACE CHARACTERISTICS

<table>
<thead>
<tr>
<th>NATURE OF THE DATA</th>
<th>SOURCE</th>
<th>COLLECTION</th>
<th>DEFAULT VALUE *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantities implemented total activity spectrum</td>
<td>RP</td>
<td>Recommended</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Frequency and duration of exposure</td>
<td>Employer</td>
<td>Recommended</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Air environment data (continuous + incidents, etc.)</td>
<td>RP</td>
<td>Supplementary</td>
<td>Depending on the area</td>
</tr>
<tr>
<td>Possible routes of intake: inhalation, cutaneous</td>
<td>RP</td>
<td>Supplementary</td>
<td>Inhalation</td>
</tr>
<tr>
<td>Collective protection means (isolation, glove box, fume cupboard, diked areas, etc.)</td>
<td>RP</td>
<td>Supplementary</td>
<td>No protection</td>
</tr>
<tr>
<td>Individual protection means (masks, impervious, ventilated garments, etc.)</td>
<td>RP</td>
<td>Supplementary</td>
<td>No protection</td>
</tr>
<tr>
<td>Feedback on measurements results and on doses</td>
<td>Occupational health practitioner</td>
<td>Supplementary</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Number of workers exposed</td>
<td>Employer</td>
<td>Recommended</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

* In case of a lack of information
exposure data sheet must be forwarded to the occupational health practitioner before the medical occupational health examination prior to exposure is carried out. Likewise, it is recommended that the work exposure data sheet should mention, based on the elements required in §2 and §4 aforementioned, the assessment of the average dose likely to be received by the worker under ordinary conditions at his/her workplace.”

disregard radionuclides the sum of whose contributions in increasing order is likely to be less than 1 mSv per year.”

ICRP 78 [2-13; 1998]

Already quoted, namely §11 and §16 concerning the interpretation of workplace monitoring data (see Topic B-1)

Reminder

(§76) “Static air samplers … can underestimate concentrations in air in the breathing zone of a worker, typically by a factor of up to about 10”

INTERNATIONAL STANDARDS AND RECOMMENDATIONS

ISO 20553 [3-1; 2006]

Depending on the level of exposure, the standard (Figure 1) recommends:

– monitoring at the workplaces, including the measurement of surface and air contamination levels, or nasal mucus sample collection, when the likely committed effective dose level may exceed 1 mSv,
– individual monitoring, including in vivo measurements and in vitro analyses when the likely committed effective dose level may exceed 6 mSv.

(§5) “If a worker is exposed to more than one radionuclide, the design of a monitoring programme may...

LITERATURE REVIEW

The literature analysed reveals the need for rating potential exposure risks, in order to adapt the monitoring programme accordingly. Four articles provide data and even a method for evaluating these potential exposure levels. One publication [26] does not address the issue whatsoever.

CASE STUDY ANALYSES BASED ON HUMAN DATA

The 2005 article by N. Blanchin and al., already quoted in A-1 [23 – Level of Evidence 2] is a reference for the weighting of exposure risks at the workplace based on quantifiable data:

– activity measurements (in Bq) at the workplace and on the equipment used,
– the time spent at the workplace expressed in hours / day,
– and the feedback on the contamination events quantified as well: number of workplace confinement breaches per semester.

This reference provides an operational classification, presented in the form of a logical diagram of the exposure risks with 4 proposed levels: potential, low, medium or significant.

The 2003 article by B. Le Guen and al. in 2003, already quoted in A-1 [120 – Level of Evidence 2] retains 2 monitoring programmes for the workplaces at risk for alpha emission:

– a collective monitoring programme involving workplace air monitoring supplemented by individual measurements on a sample of workers when the potential dose is lower than 1 mSv / 12 months,
– individual monitoring if the work situation may potentially lead to doses higher than 1 mSv / 12 months.

The 1998 article by B. Gibert and al., already quoted in B1 [74 – Level of Evidence 2] describes an approach where the exposure risk evaluation is based partly on the worker’s appraisal; the latter may request that individual monitoring measurements be run when he/she deems that an operation may present a particular risk or if an unusual event occurs.

DESCRIPTIVE ASSESSMENT OF INDIVIDUAL MONITORING

The 2006 article by J.D. Boice and al. [26 – Level of Evidence 2] is a descriptive assessment of the individual monitoring of a cohort of 5,801 nuclear industry employees, including 2,232 with a history of internal exposure risks involving different radionuclides.
radionuclides (alpha – beta – gamma) over the 1948 - 1999 period. The purpose of the study was to perform the dosimetric reconstitution for the workers of this cohort by selecting internal exposure subjects who had one organ receiving more than 10 mSv. Routine monitoring was based upon individual measurements including mainly in vivo, supplemented by quarterly urine analyses for employees at “high risk for contamination”.

**METHODICAL APPROACH**

K. Henrichs’ 2007 article already quoted in A-1 [91 - Level of Evidence 4], proposes the following classification for the potential exposure risks at the workplace:

– insignificant if the potential dose is less than 1 mSv, thereby requiring no systematic monitoring,

– low if the potential dose ranges from 1 mSv to 6 mSv, thereby requiring collective monitoring (based on tests carried out on a sample of employees) or workplace air monitoring,

– high if the potential dose is greater than 6 mSv, thereby requiring systematic individual monitoring.

This type of classification must be re-evaluated upon every change of procedure or of the working conditions.

**AUTHOR’S OPINION**

K. Henrichs’ 1998 article, already quoted in A-1 [90- Level of Evidence 4], proposes that the monitoring programme should monitor any intake exceeding 3% of the annual limit. [WG’s note: i.e., 0.6 mSv]

All of the threshold values proposed for implementing individual monitoring range from 0.6 mSv [90] to 6 mSv [91 – Standard ISO 20553].

The original approach [74] is noteworthy, since it is based on the perception of employees for triggering individual monitoring. This approach is interesting, though it is more like workplace monitoring. Moreover, the subjectivity of this approach entails a risk of over- or under-prescription.

**TO SUMMARIZE**

The regulations and the international or normative references require the implementation of monitoring according to the data obtained from the workplace, but do not provide any operational answers.

Similarly, there are few indications in the literature regarding any method for weighting the risk of exposure or the implementation thresholds.

Only two publications [23-74] provide decision criteria.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>3/1*-2/13* – 23-26-74-90-91-120</td>
<td>2* 4 2</td>
</tr>
</tbody>
</table>
IN CONCLUSION, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.

**HOW SHOULD THE RISK OF EXPOSURE BE WEIGHTED?**

The WG considers that it is important to have an approach for weighting the risk of exposure at the workplace.

This approach takes into account the feedback on the contamination events at the workplace and the implementation of collective protection measures. It does not take into account the wearing of individual protection equipment, since it is never possible to guarantee that these are correctly worn.

<table>
<thead>
<tr>
<th>THRESHOLDS DEPENDING ON THE DOSE LEVEL</th>
<th>For the potential exposure level</th>
<th>For implementing individual monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulations</td>
<td>Not specified</td>
<td>Not specified</td>
</tr>
<tr>
<td>ICRP 78</td>
<td>Not specified</td>
<td>“Significant” risk of exposure</td>
</tr>
<tr>
<td>Standard ISO 20553</td>
<td>1 mSv &lt; risk of exposure &lt; 6 mSv:</td>
<td>Collectively-oriented individual monitoring</td>
</tr>
<tr>
<td></td>
<td>Risk of exposure &gt; 6 mSv</td>
<td>Individually-oriented monitoring</td>
</tr>
<tr>
<td>[23]</td>
<td>Logical diagram enabling the risk of exposure to be classified as potential, weak, medium or significant</td>
<td>From the “medium” exposure risk</td>
</tr>
<tr>
<td>[120]</td>
<td>&lt; 1 mSv</td>
<td>Collectively-oriented individual monitoring</td>
</tr>
<tr>
<td></td>
<td>&gt; 1 mSv</td>
<td>Individually-oriented monitoring</td>
</tr>
<tr>
<td>[74]</td>
<td>Operation deemed to be a risk by the employee or perceived as an abnormal situation</td>
<td>Performed at the request of the employee or in case of an unusual event</td>
</tr>
<tr>
<td>[26]</td>
<td>Not specified</td>
<td>High risk of exposure</td>
</tr>
<tr>
<td>[91]</td>
<td>Low 1 mSv &lt; risk of exposure &lt; 6 mSv:</td>
<td>Collectively-oriented individual monitoring</td>
</tr>
<tr>
<td></td>
<td>High Risk of exposure &gt; 6 mSv:</td>
<td>Individually-oriented monitoring</td>
</tr>
<tr>
<td>[90]</td>
<td>Evaluation of the exposure risk according to probability and importance – method?</td>
<td>Risk of exposure &gt; 0.6 mSv</td>
</tr>
</tbody>
</table>
AS FROM WHAT LEVEL OF EXPOSURE SHOULD A MONITORING PROTOCOL BE SET UP?

To define the level, the WG stresses the ambiguity in the ISO 20553 standard, which explicitly states that “the detection of all yearly exposures that may exceed 1 mSv must be guaranteed”, but which only proposes the implementation of systematic individually-oriented monitoring when the risk of exposure is estimated to exceed 6 mSv.

In all cases, the WG recommends that individual monitoring be implemented whenever the estimated risk of exposure accrued over 12 consecutive months exceeds 1 mSv.

In order to guarantee the fulfilment of this objective and given the possibility of under-estimating the levels of exposure through air monitoring, individual monitoring can be triggered at lower levels, depending on whether or not it is possible to rely on collective monitoring:

– whenever it is feasible to implement collectively-oriented individual monitoring (a sufficiently large taskforce of workers with a significant level exposure risk, to allow relevant sampling), it is possible to omit the systematic monitoring of workers with an intermediate level exposure,

– on the other hand, in the absence of collectively-oriented individual monitoring, the systematic monitoring of workers at risk for intermediate exposure must be discussed.

The WG proposes the use of the value of 10 accepted by ICRP Publication 78 for the variability of the environmental parameters, related to air dispersion for defining the decision limits of the residual environmental risk (see R61).
Three levels of potential exposure risks can be defined: negligible, intermediate and significant. These correspond to indicative values that must be specified according to the technical analysis possibilities.

<table>
<thead>
<tr>
<th>MONITORING AT THE WORKPLACE</th>
<th>INDICATIVE VALUE OF THE RESIDUAL ENVIRONMENTAL RISK</th>
<th>MONITORING PROTOCOL</th>
</tr>
</thead>
</table>
| Collective protection ensures efficient and complete protection (isolation) against the risk of intake:  
  – suitable air and surface radiation protection measures constantly below the detection limits,  
  – absence of radiological events. | **NELIGIBLE**  
  \(< 0.1 \text{ mSv}\) | **No routine monitoring.**  
  Sporadic control monitoring to check for the absence of intake above 1 mSv. |
| Collective protection insufficient to ensure the complete absence of internal exposure:  
  – incomplete collective protection: diked area, fume cupboard  
  – confinement breaches occur often (ex.: glove box)  
  – individual protection equipment must regularly supplement the collective protection means. (masks, impervious garments, etc.) | **SIGNIFICANT**  
  \(> 1 \text{ mSv}\) | Implementation of routine dosimetric monitoring, respecting the maximal monitoring intervals (R 14); bioassay measurements with prior zone exclusion, if possible.  
  The bioassay measurements of the persons concerned shall be distributed throughout the year.  
  In the event of a result greater than the DRL (R43):  
  – control bioassay measurements of the worker and his/her colleagues.  
  – radiation protection survey. |
| Intermediate situation between the two above | **INTERMEDIATE**  
  \(0.1 < < 1 \text{ mSv}\) | It is legitimate to omit an individual monitoring when it is possible to rely on the collectively-oriented individual monitoring of workers at significant risk for exposure.  
  If such monitoring is not possible (insufficient sample of subjects at significant risk), it is recommended to set up routine monitoring to validate the absence of intakes and contribute to improving radiological cleanness (optimization). |
**REGULATION**

**LABOR CODE IN FORCE ON 31/12/2010 [1-1]**

(R 4451-62) “...When the exposure is internal, [reference] dosimetric monitoring shall be performed by means of in vivo measurements or in vitro analyses…”

**INTERNATIONAL STANDARDS AND RECOMMENDATIONS**

**NF ISO 20553 [3-1; 2006]**

(§7-3) “Individual monitoring of radionuclides can be made by in vivo measurements or in vitro analyses, by taking continuous air samples using individual air-sampling devices or by a combination of all these methods.”

The 3 tables (3, 4 and 5) present the measurements to be prescribed according to the contaminating radionuclides.

“The measurement frequency required for a routine monitoring programme depends on the retention and excretion of the radionuclide, the sensitivity of the available measurement techniques and the uncertainty that is acceptable when estimating annual intake and committed effective dose […] If exposure to more than one radionuclide cannot be ruled out, this requirement shall be adjusted accordingly so that a total annual dose of 1 mSv can reliably be detected and assessed. […] The maximum potential underestimation shall not exceed a factor of three.”

ICRP 78 [2-13; 1998]

(§84) “The required frequency of measurements in a routine monitoring programme depends upon

**LITERATURE REVIEW**

**METHODICAL APPROACH**

K. Henrichs’ 2007 article already quoted in A1 [91 – Level of Evidence 4] discusses the two criteria proposed by the ISO 20553 standard enabling the frequency of the systematic measurements to be determined:

1. to guarantee that any intake above 1 mSv (recording level) can be detected, even in the hypothetical event of it occurring on the day after a previous measurements
2. to guarantee that the dose estimate made based upon the hypothesis of a “mid interval” intake does not underestimate the dose by more than a factor of 3, as compared to the hypothesis of an intake occurring on the day after a previous measurements.

The 2003 article by G. Etherington and al. [64 – Level of Evidence 4] provides an overview of a European programme, OMINEX, to optimize the monitoring of exposed workers. The authors present the conditions for implementing monitoring programmes for the most common radionuclides, the measurement techniques and the related uncertainties. This article made it possible to support the recommendations of the ISO 20553 standard, as well as the approach of this document. No data is provided in this document, but the monitoring implementation principles for uranium, thorium, iodine and caesium are presented.

**CASE STUDY ANALYSES BASED ON HUMAN DATA**

The 2005 article by N. Blanchin and al., already quoted in A1 [23 – Level of Evidence 2] describes the routine monitoring programme implemented to monitor risks of exposure to actinide oxides:

– analyses of faeces performed at 6-month intervals in the case of a significant risk of exposure and on a yearly basis in the case of a medium risk,
– with no preliminary exclusion period,
– supplemented by annual in vivo measurement.
In the case of a sufficiently large number of subjects, collectively-oriented individual monitoring can replace individual monitoring to assess low or potential exposure risks.

The 2003 article by B. Le Guen and al., already quoted in A1 [120 – Level of Evidence 2] specifies that the faecal samples used for monitoring exposure to alpha emitters are collected after a 4 to 10 day exclusion period.

The 1998 article by B. Gibert and al., already quoted in B1 [74 – Level of Evidence 2] presents the routine monitoring programme implemented to monitor the internal exposure risk of employees exposed to different chemical forms of uranium. This systematic individual monitoring includes:

- air monitoring by means of a PAS (personal air sampler),
- in vivo measurements,
- analyses using fluorescence spectroscopy / 2 months (collected after a 2 to 3 day exclusion period)
- urinary controls in case of results greater than PAS operational values,
- finally, urine analyses (3 days in a row subsequent to the event) can be performed at the request of the employee when the operation is deemed at risk or upon occurrence of an unusual event.

### DESCRIPTIVE ASSESSMENT OF INDIVIDUAL MONITORING

The 2007 article by L. Bertelli and al. already quoted in B1 [11 – Level of Evidence 2] gives some indications of the monitoring intervals selected for individual routine monitoring at Los Alamos in 2005:

- urinary tritium by liquid scintillation: 1 analysis / 15 days
- urinary uranium measurement: 1 analysis / 15 days
- urinary americium: 1 to 2 analyses / year
- urinary plutonium: 1 to 2 analyses / year
- ICPMS plutonium analysis: 1 to 2 analyses / year

The 2003 article by N. Stradling and al. [166 – Level of Evidence 4] sets forth a methodological approach for the determination of the monitoring interval most suitable for the different types of measurements (in vivo measurement, analyses of urine and faeces) for the different chemical forms of uranium ($\text{UO}_3$, $\text{U}_3\text{O}_8$, $\text{UO}_2$). The authors determine the largest interval (with a minimum of one measurement /year) allowing the detection of a 6 mSv/year dose, referred to as the investigation level.

The following monitoring intervals are retained:

<table>
<thead>
<tr>
<th></th>
<th>In vivo</th>
<th>Urine</th>
<th>Faeces</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{UO}_3$</td>
<td>not applicable</td>
<td>90 days</td>
<td></td>
</tr>
<tr>
<td>$\text{U}_3\text{O}_8$</td>
<td>180 days</td>
<td>90 days</td>
<td>90 days</td>
</tr>
<tr>
<td>$\text{UO}_2$</td>
<td>180 days</td>
<td>90 days</td>
<td>90 days</td>
</tr>
</tbody>
</table>

Monitoring is based on:

- workplace air monitoring using individual portable devices and static collection devices operated at the workplace.
- nasal mucus swab tests at the end of each shift (level of action = 0.3 Bq)
- urine analyses
- faecal measurement for alpha emitters (especially Pu – Am).

Faecal monitoring is carried out by way of sampling based on one analysis per month on one employee serving as an indicator for the rest of the group (principle of uniformly exposed group). This rationale is partly due to the poor acceptance of this type of measurement by employees (Topic B-5).

The 1994 article by A. Dalheimer and al. [44 – Level of Evidence 4] discusses the procedures for the individual monitoring of workers exposed to...
Thorium contamination, as well as the limits of the body and excreta measurements. This article suggests that additional methods, such as the measurement of the thorium levels in expired air samples, be developed. Other than for this method-proposal contribution, it is not relevant.

**Author’s Opinion**

K. Henrichs’ 1998 article, previously quoted in A1 [90 – Level of Evidence 4] specifies the type of measurements to be carried out depending on the nature of the radionuclides:

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature review</th>
<th>Level of evidence</th>
</tr>
</thead>
</table>

**To Summarize**

The literature review shows that these recommendations are mostly followed and, hence, the various authors do not explain or justify the choice of measurements prescribed.

**To Conclude, the Working Group Has Ruled on the Following Issues and Makes the Following Recommendations.**

From the ICRP recommendations and from all of these publications, the WG retains the following elements:

- Depending on the physicochemical nature of each radionuclide:

<table>
<thead>
<tr>
<th>Type of absorption</th>
<th>Solubility</th>
<th>Examples</th>
<th>Sample</th>
<th>ICRP 78</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>“soluble”</td>
<td>caesium, iodine, tritium</td>
<td>urine</td>
<td>($69)</td>
</tr>
<tr>
<td>M</td>
<td>moderately “soluble”</td>
<td>plutonium nitrate, americium</td>
<td>urine and/or faeces</td>
<td>($68,69,70)</td>
</tr>
<tr>
<td>S</td>
<td>“insoluble”</td>
<td>Oxide compounds</td>
<td>faeces</td>
<td>($68,70)</td>
</tr>
</tbody>
</table>

- Depending on the type of radioactive emission:
  1. for gamma emitters (fission products and activation products): there is a choice between in vivo measurement and measurements of excreta, possibly combined
  2. for beta emitters: urine analyses
  3. for tritium: urine analyses with a possibility of carrying out additional saliva-derived measurements [115]
  4. for transuranic elements (americium, plutonium): measurement of excreta
  5. for uranium:
     a. urine analyses for soluble (class F or M) compounds,
b. urine analyses supplemented by faecal analyses for compounds of limited solubility (class S),
6. for thorium: analyses of excreta
7. the importance, within the framework of task-related monitoring (or worksite monitoring) of regular nose-blowing to screen for potential inhalation intake. This is particularly useful for diagnosing and dating the possible intake of alpha emitters.

A synthesis of the various types of analyses available together with their respective detection limits is presented in tables under Topic B-4.

R. 14 | **What routine monitoring protocol should be set up?**
What should the nature of the measurements be? (GRADE A)

The measurements prescribed according to the contaminating material are those covered by Standard ISO 20553 (R 33-34).

**TO SUMMARIZE**

Within the framework of routine monitoring, the time of intake is usually not well known. ICRP Publication 78 [2-13] proposes that a single event occurring at the middle of interval be assumed (the so-called “mid-point” method). Individual monitoring intervals are then defined so as to guarantee that the mid-interval hypothesis does not overestimate and, more importantly, does not underestimate the actual intake by more than a factor of 3.

Standard ISO 20553 [3-1] restates this principle and adds another condition, which must enable the guaranteed detection of any exposure above 1 mSv, accumulated over 1 year.

In practice, the use of the indicative monitoring intervals recommended by Standard ISO 20553 makes it possible to guarantee that the 1 mSv recording level over 12 consecutive months will not be reached, whatever the date of occurrence of the intake in the interval of interest.

This is guaranteed by the analytical performance of the laboratory measurements obtained in laboratories such as those presented in Topic B-4-3.

The literature review shows that the routine monitoring protocols use the intervals of confidence recommended by Standard ISO 20553.

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The literature review shows that the routine monitoring protocols use the intervals of confidence recommended by Standard ISO 20553.

**TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.**

The WG does not retain the isolated position, which concerns a specific form of the tritium compound.

The WG recommends the values set forth by the standard (presented in Tables 3, 4 and 5 of Standard ISO 20553) for the definition of the monitoring intervals, which allow:
1. the professional practices followed up until now by on-site practitioners to be preserved,
2. the reference values used mostly at the international level to be kept,
3. consistency to be maintained with the other reference values used: particle size, type of absorption, etc., as recommended in Topic C-1.

Moreover, in agreement with Standard ISO 20553 and the literature review, as well as with the unpublished professional practices, the WG retains the rule that individual-oriented routine monitoring should include at least one analysis per year.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>3/1*-2/13*&lt;br&gt;11-23-25-44-64-74-90-91-120-160-166</td>
<td>2* 4 1 6</td>
</tr>
</tbody>
</table>

TO SUMMARIZE

Within the framework of routine monitoring, the time of intake is usually not well known.

ICRP Publication 78 [2-13] proposes that a single event occurring at the middle of interval be assumed (the so-called “mid-point” method). Individual monitoring intervals are then defined so as to guarantee that the mid-interval hypothesis does not overestimate and, more importantly, does not underestimate the actual intake by more than a factor of 3.

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</thead>
<tbody>
<tr>
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<td>3/1*-2/13*&lt;br&gt;11-23-25-44-64-74-90-91-120-160-166</td>
<td>2* 4 1 6</td>
</tr>
</tbody>
</table>
To ensure the continuous monitoring of a given workplace, the measurement of the various persons involved shall be performed at different times for each person throughout the period of exposure, while respecting the monitoring interval for each person. This monitoring enables collective monitoring based on a sampling principle.

When the monitoring of a workplace is carried out continuously under the conditions mentioned, it is not necessary to monitor the less exposed persons (negligible residual risk).

The maximal monitoring intervals according to the contaminating material are those indicated by Standard ISO 20553 (R43).

When the prescribed measurement has a different detection limit from that indicated by Standard ISO 20553, the monitoring interval can be recalculated (without exceeding 1 year).

When the exposure data for a given radionuclide is not specified (intake mode and/or radionuclide characteristics), it is recommended that the shortest interval be used.

The measurements provided for within the framework of a routine monitoring protocol must be conducted:
– at least once a year, either by means of an *in vivo* and/or an *in vitro* measurement,
– and also, prior to the beginning of any exposure to constitute the ‘point zero’ value and in order to guarantee the absence of any residual contamination related to some former exposure likely to skew the dosimetric evaluation during a later exposure, – at the end of the exposure period, regardless of the date of the last measurement.

Reports the choice of non-exclusion prior to measurement, within the framework of routine monitoring of exposures to transuranic elements via faecal analysis.

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The WG summarizes the advantages and the disadvantages of each of the options (with or without exclusion) in the table below and leaves the occupational health practitioner free to decide.

<p>| ADVANTAGES AND DISADVANTAGES OF EXCLUSION ZONING PRIOR TO SAMPLE COLLECTION IN ROUTINE MONITORING |
|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|</p>
<table>
<thead>
<tr>
<th>CONSTRAINTS</th>
<th>IN TERMS OF OBSERVANCE</th>
<th>IN TERMS OF DOSIMETRIC ASSESSMENT</th>
<th>IN TERMS OF COLLECTIVE MONITORING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WITH EXCLUSION</strong></td>
<td>Disrupts work activity</td>
<td>Dosimetric interpretation possible</td>
<td>The sampling principle is difficult to apply since it is often conducted during stoppage periods</td>
</tr>
<tr>
<td><strong>WITHOUT EXCLUSION</strong></td>
<td>Does not disrupt work activity</td>
<td>Risk of overestimation during the interpretation phase Requires control testing in case of a result greater than the DRL</td>
<td>Conducted on a “continuous basis” throughout the year Also enables radiological cleanliness monitoring</td>
</tr>
</tbody>
</table>

TO SUMMARIZE

ICRP Publication 78 emphasizes the fact that an abnormal finding obtained during routine sample collection without prior zone-exclusion must be controlled by post-exclusion sample analysis. Only the 2005 article by N. Blanchin and al [23]...
Within the framework of routine monitoring, the decision of exclusion before sampling depends on the population exposed (number and level of risk), as well as on the previous results:

- If results are consistently positive, it is advisable to proceed with preliminary exclusion,
- If results are consistently negative, it is advisable to proceed with the sampling without exclusion in favour of implementing continuous monitoring staggered over the year.

**REGULATION**
No specific requirement can be found, except for the requirements in connection with the risk evaluation:

- drafting of a single document (Art. L.4121-3) and yearly updates,
- updating the company sheet (Art. D.4624-97).

**INTERNATIONAL STANDARDS AND RECOMMENDATIONS**

**ISO 20553 [3-1; 2006]**

Control monitoring

(§7-3) “Confirmatory monitoring programmes can be required to check the assumptions about exposure conditions underlying the procedures selected, e.g. the effectiveness of protection measures. It may consist of workplace or individual monitoring…”

**ICRP 78 [2-13; 1998]**

Confirmation monitoring

(§86) “One method of confirming that working conditions are satisfactory is to carry out occasional individual monitoring. Such measurements can be interpreted only qualitatively, but unexpected findings would give grounds for further investigation.”

**LITERATURE REVIEW**

**CASE STUDY BASED UPON HUMAN DATA**

The 2005 article by N. Blanchin and al., already quoted in A1 [23 – Level of Evidence 2] stresses the importance of carrying out regular review analyses of the routine monitoring results to validate the relevance of the initial evaluation of exposure risks at the workplace. This validation is dependent upon such regular review analyses of the measurements, whose relevance and consistency are assessed in terms of the objectives set forth.

**METHODICAL APPROACH**

K. Henrichs’ 2007 article already quoted in A1 [91 – Level of Evidence 4] stresses the need to reassess all monitoring protocols every time there is a change in the process, or in the working conditions and to check that the protocol always meets the initial objectives.

**PHYSICS DOCTORATE THESIS**

The thesis of E. Davesne in 2010 [48 – Level of Evidence 4] is concerned with the uncertainties in the dosimetric interpretation of routine bioassay measurements that are introduced by their own variability and by the incomplete knowledge of the contamination conditions. These uncertainties were taken into account by classical and Bayesian probabilistic techniques.

The method developed was applied to the evaluation of potential exposure during the manufacturing of nuclear fuel and in uranium mines, as well as to the analysis of the monitoring programme for the workers in the plutonium purification workshop of the AREVA NC site in La Hague.

Starting from the nuclear counting decision threshold, the minimum detectable dose (MDD) by the monitoring programme with a given level of confidence can be calculated using the “OPSCI” software (optimization of internal contamination monitoring programmes). This has proven to be a useful tool for optimizing monitoring programmes by seeking the best compromise between their sensitivity and cost.

The method and its application to the plutonium monitoring programme at the AREVA site in La Hague are discussed in 3 articles [49-50-51- Level of Evidence 4]

**UNPUBLISHED FEEDBACK**

This analysis can be supplemented by the [unpublished] feedback from the routine monitoring programmes at EDF:

- concerning the monitoring of exposure to tritium from 1980 to 1986: the overall analysis conducted on the results from periodic sample collections (one analysis per year and per exposed worker) has made it possible to conclude the implementation
of worksite monitoring (involving sample collection carried out near the date of exposure) would be advisable, rather than maintaining a monitoring programme where sampling is carried out at pre-set intervals throughout the year.

- concerning routine monitoring of exposure to gamma emitters: the overall analysis conducted on the results from regular measurements (both in vivo and in vitro – urine - at least once per year) implemented since the 1960’s up until around 1985 for all exposed workers, has shown the redundancy of such double monitoring. Only in vivo measurements (higher acceptability and feasibility levels) were maintained.

TO SUMMARIZE

The minimum detectable dose (MDD) by a monitoring programme is defined as the committed effective dose corresponding to the highest contamination that would not be detected, i.e., which would only lead to measurement results below the detection limit. The activity and dose assessment uncertainties can be represented in terms of probabilities, so as to calculate, under such uncertainties, an MDD value with a given level of confidence. Thus, an annual MDD of 1 mSv with a 95%-level of confidence means that when the yearly measurements are negative, there is only a 5% risk of the committed effective dose received exceeding 1 mSv.

In a simplified way, to express the MDD taking into account only the uncertainties concerning the time of intake and the activity counting, the Working Group has retained (with a 95% level of confidence) the following formula:

$$\text{MDD} = \frac{\text{Detection limit} \times \text{dose coefficient}}{\text{retention or excretion function at the end of the monitoring period}}$$

Thus, when the monitoring period in place at a NI does not comply with the value recommended in Standard ISO 20553, the MDD allows the magnitude of the committed effective doses that may possibly be received to be estimated without the corresponding intake being detected by the monitoring programme.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>3/1*-2/13* – 23-48-49-50-51-91</td>
<td>1 2 3 4</td>
</tr>
</tbody>
</table>

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The WG retains, from the literature analysis, the need to validate the relevance of a routine individual monitoring programme. It is necessary to check regularly that the results derived from this monitoring are consistent with the levels of risk used in drawing up this programme. In case of an inconsistency, the levels of risk should be reassessed.

The use of the minimum detectable dose (MDD) allows the relevance of a systematic individual monitoring programme to be corroborated. The OPSCI software, which applies it, is currently only available to experts, but may, in the future, be made available to occupational health practitioners.

R. 15 | How can the relevance of the monitoring programme be checked? what should be done if the protocol is not heeded? (Professional agreement)

If the risk evaluation yields a “negligible” weighting value and, hence, points to the absence of routine monitoring, a control monitoring on all of the persons involved, or on a representative sample, can be prescribed to confirm the absence of any intake that could lead to a cumulated dose greater than 1 mSv over 12 consecutive months. The elements necessary for its implementation are identical to those implemented for a routine monitoring programme.

The programme is limited in time and is subject to evaluation upon completion to determine whether it is justifiable to:

- interrupt it (thereby validating that routine monitoring is not to be implemented),
- or, on the contrary, sustain it as a routine monitoring programme.

If the risk evaluation yields a weighting value that is “intermediate” or “significant”, hence pointing
Any change in the workplace or of the measurement techniques used, requires that the protocol be revised.

Finally, if the monitoring protocol has not been followed:
– the non-respect of the same must be recorded in the medical file,
– the dosimetric effect must be evaluated, which may cause the ability to work at the workplace to be reconsidered.

At the same time, the workplaces are regularly monitored and the risk weightings reassessed, in order to validate the maintenance of the monitoring protocol in place.

This chapter introduces the operational bases (methods and means) necessary to set up special monitoring programmes to address the following questions:
– What are the items needed to carry out the analysis of the event? **Stage 1**
– What grade levels of the risk of exposure must be retained? What are the relevant exposure indicators, and how do we interpret their results in order to define the initial rating? **Stage 2**
– What protocol (type and frequency of the measurements) and what type of follow-up should be put in place? **Stage 3**
– On what criteria is the relevance of the programme to be validated? **Stage 4**

This concerns situations of abnormal radiological events, either real or suspected.

**B-3 | SPECIAL MONITORING (POST-EVENT)**

The logical diagram below is a synthesis of the stages whose content is discussed under the following sub-topics.

For the understanding purposes, it is inserted at the beginning of this chapter.
REGULATIONS

LABOR CODE IN FORCE ON 31/12/2010 [1-1]
(R 4451-97) “The employer develops the installations and takes all measures useful so that, in case of an accident:
1°) Workers may be rapidly evacuated from the work premises.
2°) Exposed workers may receive, when their condition of exposure, so it is difficult to standardize special workplace monitoring.”

ISO 20553 [3-1 ; 2006]
(§8.1) “Special monitoring programmes shall be conducted following events to provide data for – dose assessment required for estimating risk and determining the need for any treatment; – radiation-protection optimization process.”

(§8-3) “The goal of special individual monitoring is to ensure that any intake is detected at an early stage and that the associated committed doses are evaluated.”

ICRP 78 [2-13 ; 1998]
(§85) “Special monitoring refers to monitoring carried out in actual or suspected abnormal situations.”

This document provides in its appendices indications per item on the radio-toxicological tests to carry out after suspected inhalation or when a wound is suspected of being contaminated.

LITERATURE REVIEW

CASE STUDY ANALYSES BASED ON HUMAN DATA
2004 article by N. Blanchin and al. already mentioned in A1 [22 – Level of Evidence 2] is an authoritative reference document on weighting risks of actinides oxide inhalation in case of confinement breach, based on:
– the level of air contamination increase, as expressed in DACL.h (Derived Air Concentration Limit measured in Bq/m3)
– the result of nasal mucus analysis expressed in Bq.

2008 article by G. Miller and al. [135 – Level of Evidence 2] explains the application of a Bayesian iterative method for intake and dose assessments in 210 workers exposed to plutonium in 1944-1945 at the Los Alamos centre (USA). The interpretation of the measurements is complicated by the poor quality of the data, in particular consecutive to the presence of highly contaminated samples following biological sample collection.

The authors also emphasize the difficulties related to late reconstruction of the measurement: estimates of background noise, chemical yield, and measurement uncertainty were introduced many years after the measurements. Only a few results are available. Those that are very high are not controlled. There is no other source of information remaining that would allow one to know whether the worker was implicated or not in an incident thereby confirming such high results.

METHODICAL APPROACH
2008 EM Brackett’s article [29 – Level of Evidence 4] concerns the NIOSH method (National Institute for Occupational Safety and Health) for reconstitution of internal doses within the framework of...
occupational disease recognition. Owing to the difficulty involved in obtaining case history data, the NIOSH has adopted a set of default values retaining the most applicant-oriented hypotheses every time many plausible choices are possible.

TO SUMMARIZE

When an event is made known to the occupational health practitioner, it is paramount that the latter should possess a certain number of elements in order to evaluate the severity of the event and to define the actions to be taken (protocol). The regulations, the normative and international recommendations and the literature do not specifically address this issue since it is considered obvious.

An analysis of the post-event publications relating on dose reconstitution show the difficulties encountered in collecting initial data after a delay [135] [29].

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3/1*-2/13* – 22-29-135</td>
<td>2* 2 1</td>
</tr>
</tbody>
</table>

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The WG recommends collecting the elements needed to analyse the event and potential severity thereof:
- elements of exposure at the workplace,
- collective and individual protections displayed during the operation,
- circumstances of the event,
- results from environmental measurements and collective and individual bioassay measurements.

The recommended data is the data that is the easiest to obtain without special investigation, and the complementary data is the data that requires thorough investigation.

The elements necessary to set up of a special monitoring programme following a contamination event are formalized in a document that was drawn up in consultation with the Radiation Protection Officer and the Occupational Health Service.

This document herein referred to as “radiological event sheet” must rely on the analysis of realistic scenarios of radiological event occurrence at the workplace and provides for:
- Establishing a rating of the risk of exposure during a particular event,
- Meeting the objectives of individual monitoring as defined under R1,
- Collecting the data for the assessment of the committed effective dose.

In the case of a non-identified event, following the discovery of a positive sample during routine monitoring, the special monitoring programme relies on the result of the first individual measurements. If this result is greater than the derived recording level (R 43), a confirmation measurement is carried out. If the result is confirmed, a special monitoring programme is then set up.

In the case of an identified event, the special monitoring programme relies on the data contained in the radiological event sheet, which determines the next two stages:
- prescription of dosimetric measurements according to the operational level thus retained.

R. 17 | What elements are necessary to carry out the analysis of an event within the special monitoring framework? (Professional agreement)
### INFORMATION ON THE MATERIAL

<table>
<thead>
<tr>
<th>Nature of the information</th>
<th>Source</th>
<th>Collection</th>
<th>Default value *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radionuclides or isotopic composition</td>
<td>Radiological event Sheet</td>
<td>Recommended</td>
<td>Type of emitters</td>
</tr>
<tr>
<td>Physical form (liquid – solid – gas)</td>
<td>Radiological event Sheet</td>
<td>Recommended</td>
<td>The most disadvantageous as per DPUI values</td>
</tr>
<tr>
<td>Chemical form (oxide, nitrate, etc.)</td>
<td>Supplementary</td>
<td>Table 3-3 - Decree dated 01/09/2003[1-3]</td>
<td></td>
</tr>
<tr>
<td>AMAD (particle size)</td>
<td>Supplementary</td>
<td>5 micrometers (ISO 27048 standard)</td>
<td></td>
</tr>
</tbody>
</table>

### CIRCUMSTANCES OF EXPOSURE

<table>
<thead>
<tr>
<th>Nature of the information</th>
<th>Source</th>
<th>Collection</th>
<th>Default value *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levels of surface contamination (location and levels)</td>
<td>Radiation Protection (RP)</td>
<td>Recommended</td>
<td></td>
</tr>
<tr>
<td>Air data</td>
<td>RP</td>
<td>Recommended</td>
<td>“High”</td>
</tr>
<tr>
<td>Level of external contamination (dermal and/or clothing)</td>
<td>RP + OHS</td>
<td>Recommended</td>
<td></td>
</tr>
<tr>
<td>Operational dose determination</td>
<td>RP</td>
<td>Recommended</td>
<td></td>
</tr>
<tr>
<td>Possible routes of intake: inhalation, ingestion, percutaneous or dermal</td>
<td>RP</td>
<td>Supplementary</td>
<td>Inhalation</td>
</tr>
<tr>
<td>Collective protection means (isolation, glove box, fume cupboard, diked area, etc.),</td>
<td>RP</td>
<td>Recommended</td>
<td>No protection</td>
</tr>
<tr>
<td>Individual protection means (mask, impervious, ventilated outfits, etc.).</td>
<td>RP + actor</td>
<td>Recommended</td>
<td>No protection</td>
</tr>
<tr>
<td>Feedback on measurement results and on doses</td>
<td>RP + OHS</td>
<td>Supplementary</td>
<td></td>
</tr>
</tbody>
</table>

* In case of lack of information
B-3-3 | STAGE 2: A SPECIAL INITIAL MONITORING PROTOCOL TO ESTIMATE THE RISK OF EXPOSURE (INITIAL RATING)?

– What rating levels should be retained for the exposure risk? (Initial rating)
– What are the relevant exposure indicators and how should their values be interpreted in order to define the initial rating?

Q. | What rating levels should be retained for the exposure risk? (Initial rating)

REGULATIONS
No reference

INTERNATIONAL STANDARDS AND RECOMMENDATIONS
No reference

EUROPEAN WORKING GROUP REPORTS
IDEAS GUIDELINES [56; 2006] LEVEL OF EVIDENCE 2
§ 5-2 of these guidelines differentiate 4 levels of complexity in the evaluation of the committed effective dose to be applied according to the expected order of magnitude of the dose:
- At Level 0, when the measured activity is lower than a previously determined threshold value, according to the measurement interval and the biokinetic model, the annual dose is presumably less than 0.1 mSv and no other dosimetric evaluation is necessary.
- At Level 1, for a dose of the order of 0.1 to 1 mSv, a simple evaluation is carried out, adopting the ICRP-recommended parameter values for lack of any specific information, that is in the form of an assumed intake at the middle of the monitoring interval, a particle size of 1 or 5 micrometers and an F, M or S absorption type.
- At Level 2, if the dose is likely to exceed 1 mSv, or in case an incident is confirmed, it is recommended that several measurements be made using various techniques and/or at different times.
- At Level 3, if the dose is estimated to exceed 6 mSv, a more sophisticated evaluation is carried out by adjusting all of the model parameters until satisfactory consistency is achieved between the values foreseen and the measurement data.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>56</td>
<td>1</td>
</tr>
</tbody>
</table>

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The exposure data, the assumptions made and the initial measurements, etc., are data used to obtain an initial rating of the event. All of this data is tainted by substantial uncertainty, which will be subsequently reduced through more precise measurements and, above all, by repeating these over time (see Topic C).

It is therefore necessary, in order to detect at least the 1 mSv dose (RL) in the end, to have a scale that takes into account initial evaluations markedly below the RL.

The WG proposes a 3-level rating – negligible, intermediate and significant – corresponding to Levels 0, 1 and 2 of the IDEAS guidelines, respectively.

These risk estimate levels allow the importance of the monitoring to be implemented to be weighed (choice of measurements and repetition over time).

No higher level has been retained, in reference to Level 3 of the IDEAS guidelines [56] (> 6 mSv), since it does not affect the special monitoring programme.
Q. What are the relevant exposure indicators and how should their values be interpreted in order to define the initial rating?

REGULATIONS

No reference

INTERNATIONAL STANDARDS AND RECOMMENDATIONS

**NF ISO 20553 [3-1; 2006]**

(§8.2) Workplace monitoring

“Devices fitted with alarms and which operate continuously should be used whenever operations or malfunctioning is likely to produce significant releases of radioactive material in the workplace.”

(§7.2) “The results of air-monitoring can be used to estimate the intake of a radioactive substance by workers but reliance on measurement of airborne activities alone can lead to errors in exposure estimates.”

(§8.3) “The analysis of nasal samples (nasal smears or nose-blowing into cellulose tissues) can supplement […] in order to give a rapid estimate of the severity of an event and valuable information on the nature of the inhaled contaminant.

**ICRP 78 [2-13; 1998]**

(§60) “In some cases of suspected incidents, screening techniques (such as measuring nose blow samples or nasal smears) may be employed to give a preliminary estimate of the seriousness of the incident. In these cases the regional deposition for ET1, given in Table 1, can be used to confirm that an intake has occurred and to give a rough estimate of the intake.”

LITERATURE REVIEW

CASE STUDY ANALYSES BASED ON HUMAN DATA

The 2004 article by N. Blanchin and al., already quoted in A1 [22 – Level of Evidence 2] offers a reference for weighing the risk of inhaling actinide oxide during a confinement breach, on three levels: negligible, intermediate and significant, based on the air contamination increase expressed in Derived Air Concentration (DAC.h), and on nasal mucus analysis results expressed in Bq, based on the following table:

<table>
<thead>
<tr>
<th></th>
<th>&lt; 10 DAC.h</th>
<th>Between 10 and 60 DAC.h</th>
<th>&gt; 60 DAC.h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative nasal sample</td>
<td>negligible</td>
<td>intermediate</td>
<td>significant</td>
</tr>
<tr>
<td>Positive nasal sample</td>
<td></td>
<td></td>
<td>significant</td>
</tr>
</tbody>
</table>
UNPUBLISHED FEEDBACK:
The levels of air contamination expressed in RPD
The initial rating of the level of severity of the event
is based on the event data provided by radiation
protection means at the workplace, in particular the
air contamination increase level. To that end, the
operational values were set by radiation protection
experts relative to the external radiological zoning.
The current baseline value is referred to as RPD
(Respiratory Protective Device), which corresponds
to activity leading to the dose of 25 microSv (lower
limit for the controlled area) by inhalation (using
values from ICRP Publication 78).

<table>
<thead>
<tr>
<th>DAC in Bq/m³</th>
<th>Respiratory Protective Device RPD</th>
<th>Corresponding dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>800</td>
<td>20 mSv</td>
</tr>
<tr>
<td>100</td>
<td>40</td>
<td>1 mSv</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>0.1 mSv</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>25 microSv</td>
</tr>
</tbody>
</table>

Remark: This item of data must be weighted if
an RTPD (Respiratory Tract Protection Device) is
worn, considering a minimum efficiency factor
(e.g. 100 for a filtering RTPD, which is a highly
underestimated value according to the feedback
from monitoring RTPD-wearing workers exposed to
air contamination increases).

TO SUMMARIZE
The normative and international recommendations
confirm the possibility of using fast-response mea-
surements to estimate the level of severity of an
event: environmental air body, nasal mucus and
urine measurements.

This first assessment does not correspond to a
reliable dosimetric estimate, as confirmed by the
publication by N. Blanchin and al. [22].

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3/1*·2/13* – 22</td>
<td>2*</td>
</tr>
</tbody>
</table>

TO CONCLUDE, THE WORKING GROUP HAS RULED
ON THE FOLLOWING ISSUES AND MAKES
THE FOLLOWING RECOMMENDATIONS.
Rapid event appraisal is necessary to guide the
protocol and the possible therapy to be started.
Furthermore, it allows any question that the wor-
k, the employer and the regulating bodies may
have to be addressed.
The feedback from unpublished professional prac-
tices has allowed a summary table to be established,
to guide the occupational health practitioner in the
choice of the initials measurements to be carried
out, as well as in their quick interpretation.

FOR INHALATION:
All of the fast-response techniques defined under
Topic B-4 can be used as an exposure indicator
allowing the exposure initial rating level to be
established.
For fast-response measurements that are not used
for dosimetric estimates, the laboratory response
can be expressed:
– relative to the detection limit (LD) of the technique,
– relative to an operational interpretation limit
defined beforehand in consultation with the pres-
criber (see Topic B-4-3),
– either literally specifying “negative” and “posi-
tive” relative to either of these two limits.
– or in reference to the Derived Recording Level
DRL (R 42), whose values per measurement are
indicated in tables R 43 and R 44).
Depending on the emitters, the level classification decision criteria are as follows:

### For Alpha Emitters

<table>
<thead>
<tr>
<th>Level</th>
<th>“Negligible”</th>
<th>“Intermediate”</th>
<th>“Significant” *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detectable external contamination localized in the head</td>
<td>Absent</td>
<td>Absent</td>
<td>Present*</td>
</tr>
<tr>
<td>Alpha measurement from a nasal mucus sample</td>
<td>&lt; interpretation limit</td>
<td>&lt; interpretation limit</td>
<td>&gt; interpretation limit *</td>
</tr>
<tr>
<td>Air Concentration Marker in the absence of any protection means for the respiratory tract</td>
<td>&lt; 4 Bq/m³</td>
<td>Ranging 4 to 40 Bq/m³ *</td>
<td>&gt; 40 Bq/m³ *</td>
</tr>
<tr>
<td>In vivo measurement for X emitters</td>
<td>&lt; LD</td>
<td>&lt; LD</td>
<td>&gt; LD *</td>
</tr>
<tr>
<td>± supplemented by results from measurements:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– of spot urine samples (soluble uranium compounds)</td>
<td>&lt; interpretation limit</td>
<td>&gt; interpretation limit *</td>
<td>&gt; interpretation limit *</td>
</tr>
<tr>
<td>– of the faeces (thick layer)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### For Gamma Emitters

<table>
<thead>
<tr>
<th>Level</th>
<th>“Negligible”</th>
<th>“Intermediate”</th>
<th>“Significant”</th>
</tr>
</thead>
<tbody>
<tr>
<td>In vivo measurement</td>
<td>&lt; LD</td>
<td>Between LD and DRL*</td>
<td>&gt; DRL *</td>
</tr>
<tr>
<td>Urinary measurement result (spot sample)</td>
<td>&lt; LD</td>
<td>Between LD and DRL*</td>
<td>&gt; DRL *</td>
</tr>
<tr>
<td>Beta/gamma measurements from nasal mucus sample</td>
<td>&lt; interpretation limit</td>
<td>&lt; interpretation limit</td>
<td>&gt; interpretation limit *</td>
</tr>
<tr>
<td>± supplemented by results from measurements on faeces without calcination</td>
<td>&lt; LD</td>
<td>Between LD and DRL*</td>
<td>&gt; DRL *</td>
</tr>
</tbody>
</table>

### For Tritium **

<table>
<thead>
<tr>
<th>Level</th>
<th>“Negligible”</th>
<th>“Intermediate”</th>
<th>“Significant” *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saliva sample</td>
<td>&lt; interpretation limit</td>
<td>&lt; interpretation limit</td>
<td>&gt; interpretation limit *</td>
</tr>
<tr>
<td>Urine measurement result (spot sampling)</td>
<td>&lt; LD</td>
<td>Between LD and DRL*</td>
<td>&gt; DRL *</td>
</tr>
</tbody>
</table>

* If at least one of the criteria is present, the level is reached
** Possibility of contamination associated with the transcutaneous route of entry

For LD values see R33- R 34 and for DRL, see R 43- R44
REGARDING THE SPECIAL CASE OF WOUNDS

The elements for decision-making are founded on the “positivity” of the measurements, regardless of the level of the same.

R. 21 | What are the relevant exposure indicators and how should their values be interpreted in order to define the initial rating following exposure via a wound or splashing onto healthy skin (Professional agreement)

### Nature of the information

<table>
<thead>
<tr>
<th>Nature of the information</th>
<th>Source</th>
<th>Collection</th>
<th>Level by default *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity measured on a blunt object</td>
<td>Radiation Protection Officer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local measurements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurements on dressings and compresses</td>
<td>OHS / Measurement Laboratory</td>
<td>Recommended</td>
<td>Significant</td>
</tr>
<tr>
<td>± supplemented by measurements on excised tissue (if surgery is involved)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement results</th>
<th>Level</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>“negligible”</td>
<td>“intermediate”</td>
<td>“significant” **</td>
</tr>
<tr>
<td>All measurements on the individual</td>
<td>&lt; LD</td>
<td>-</td>
</tr>
<tr>
<td>Measurements on the blunt object</td>
<td>&lt; LD</td>
<td>-</td>
</tr>
</tbody>
</table>

Given the dosimetric evaluation described under Topic C, it is essential to prescribe suitable and relevant in vivo and in vitro measurement. The interpretation of the results is explained under Topic C.

### B-3-4 | STAGE 3 : SPECIAL DOSIMETRIC MONITORING PROTOCOLS

Q. | What protocol (type and frequency of measurements) should be implemented?

REGULATIONS

LABOR CODE IN FORCE ON 31/12/2010 [1-1]

No reference except for those mentioned under Topic B-4-1 concerning the nature of the measurements.

INTERNATIONAL STANDARDS AND RECOMMENDATIONS

ISO 20553 [3-1 ; 2006]

(§8.3) “Special monitoring programmes are investigative; they are usually based on a suitable combination of in vivo measurements and in vitro analyses in association with the appropriate biokinetic model.”

“Table 7 summarizes recommended methods for individual monitoring; it does not take into account the effects of treatment that can be undertaken to reduce the committed effective dose.”

ICRP 78 [2-13 ; 1998]

(§9) “Any measurement should enable each radionuclide to be identified, its activity quantified and the measurement result interpreted in terms of intake or committed effective dose.”

(§60) “Monitoring in relation to a particular task or event may often involve a combination of techniques so as to make the best possible evaluation…”

---

* In the case of lack of information
** If at least one of the criteria is present, the level is reached
LITERATURE REVIEW

CASE STUDY ANALYSIS BASED UPON HUMAN DATA
The 2003 publication by E.H. Carbaugh and al. [31 – Level of Evidence 3] discusses two cases of special monitoring data following an Am-241 and Pu-239-240 inhalation event over duration periods ranging up to 6,500 days. The results of the in vivo measurements and those derived from excreta analyses are provided and interpreted. The article stresses the difficulties involved in dose assessment in the case of exposure to plutonium oxides. Such difficulties are both measurement-related (alpha spectrometry-associated detection limit) and due to the biokinetic data (lymph nodes effect).

The other articles discussed under Topic B-2-4 (chapter on routine monitoring) and related to the nature of the measurements to be prescribed are applicable to special monitoring.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3/1*-2/13* – 31</td>
<td>2* 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
</table>

TO SUMMARIZE

Standard ISO 20553 and ICRP Publication 78 provide indications on the bioassay measurements to be prescribed depending on the radionuclide, its chemical nature, etc., as well as providing data for their interpretation.

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The prescription of measurements and their repetition over time depend on the initial rating level of the event: intermediate or significant.
The measurements to be carried out are of the same nature as those prescribed for routine monitoring.
What differs is their repetition over time and the sample collection methods, which are carried out excluding any risk of exposure.
The selection of the samples to be collected and of the measurements to be conducted according to the physicochemical nature and the type of chemical nature, etc., as well as providing data for their interpretation.

emission of the compounds is explained under Topic B-2-4, routine monitoring protocol.
A summary of the various types of measurements available, together with their detection limits and the recommended monitoring intervals, is presented in the form of tables under Topic B-4.

Based on the feedback from professional practices, most of which have not been published, the WG has drawn up tables concerning the protocol to be implemented within the framework of special monitoring.

R. 22 | What special dosimetric monitoring protocol should be chosen (Professional agreement)

The monitoring protocols (nature and periodicity of the measurements) take into account the initial rating of the intake level.
No action is taken if the initial rating is of a negligible level.
If the initial exposure parameters are within significant levels, the frequency and nature of the measurements will be more important to refine the estimate of the intake.

Special monitoring measurements are continued until results fall below the detection limit or up until their stabilization (stable plateau activities).
For radionuclides that are not mentioned, it is possible to use Table 7 in Standard NF ISO 20553. [3-1]
See R 33- R 34

<table>
<thead>
<tr>
<th>CONTAMINANT</th>
<th>INTERMEDIATE LEVEL OF SEVERITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tritium</td>
<td>Urine samples</td>
</tr>
<tr>
<td>Beta emitter</td>
<td>24-hr urine collection</td>
</tr>
<tr>
<td>Gamma emitter</td>
<td>Whole-body counting</td>
</tr>
<tr>
<td>Compound F</td>
<td>Supplemented by urine analysis, depending on the radionuclide</td>
</tr>
<tr>
<td>Gamma emitter</td>
<td>Whole-body counting</td>
</tr>
<tr>
<td>Compound M</td>
<td>Supplemented by urine and/or faecal analysis, depending on the radionuclide</td>
</tr>
<tr>
<td>Gamma emitter</td>
<td>Whole-body counting</td>
</tr>
<tr>
<td>Compound S</td>
<td>Supplemented by urine and/or faecal analysis, depending on the radionuclide</td>
</tr>
<tr>
<td>Iodine</td>
<td>Thyroid measurement</td>
</tr>
<tr>
<td></td>
<td>Supplemented by urine analysis, as needed</td>
</tr>
<tr>
<td>Type-F U</td>
<td>24-hr urine</td>
</tr>
<tr>
<td>Type-M U</td>
<td>24-hr urine</td>
</tr>
<tr>
<td>Type-S U</td>
<td>day 1-, day 2- and day 3-faeces</td>
</tr>
<tr>
<td>Type-S Pu</td>
<td>day 1-, day 2- and day 3-faeces</td>
</tr>
</tbody>
</table>
Nevertheless, depending on the workplace setting (alpha emitters), failure to detect any contamination from the local measurement does not preclude the possibility of a systemic route of entry, especially in the case of a deep wound and/or of splashing onto the mucosae (eye) or healthy skin.

If the initial rating of the event is at a significant level:
- Repeat local measurements,
- Seek a systemic route of entry: measurements to be determined according to the radionuclide, see R 34.

If the initial rating of the event is at a negligible level, no action must be taken.

For radionuclides not mentioned, it is possible to use Table 7 in Standard NF ISO 20553. [3-1]

For R 33- R 34

**CONTAMINANT** | **SIGNIFICANT LEVEL OF SEVERITY**
--- | ---
Tritium | Urine (spot sample or 24-h sample) to be continued according to the evolution of the results
Beta emitter | Urine / 24 h + day 3 + day 10 with risk exclusion
Gamma emitter | Urine + Whole-body counting until results turn negative
Gamma emitter | Urine + Faeces + Whole-body measurement. Prescribed immediately at day 3 + day 10 if inhalation confirmed and with risk exclusion
Gamma emitter | Urine + Faeces + Whole-body gamma measurement. Prescribed immediately at day 3 + day 10 if inhalation confirmed and with risk exclusion
Gamma emitter | Urine + thyroid measurement until results turn negative
Type-F U | Urine + \textit{in vivo} measurement
\hspace{1cm} Prescribed immediately at day 3 + day 10 with risk exclusion
Type-M U | Faeces /72 h + Urine + \textit{in vivo} measurement
\hspace{1cm} 24-hr urine completed immediately at day 10 with risk exclusion
Type-S U | Faeces /72 h + urine + \textit{in vivo} measurement. Faeces at day 1, day 2 and day 3 completed immediately at day 10 with risk exclusion
Type-S Pu | Faeces /72 h + urine + \textit{in vivo} measurement. Faeces at day 1, day 2 and day 3 completed immediately at day 10 with risk exclusion

For radionuclides not mentioned, it is possible to use Table 7 in Standard NF ISO 20553. [3-1]

REGULATIONS
No specific requirement is found, apart from those related to the evaluation of risks:
- drawing up of the only document (Art. L.4121-3) and yearly updates,

INTERNATIONAL STANDARDS AND RECOMMENDATIONS
References indicated under Topic B-2-5 Validation of the routine monitoring programme
LITERATURE REVIEW

Only one publication mentions the issue of monitoring programme evaluation.

CASE STUDY BASED UPON HUMAN DATA

The 2004 article by N. Blanchin and al. already quoted in A1 [22 – Level of Evidence 2] describes the validation of a monitoring protocol for employees exposed to actinide oxides via the occasional prescription of measurements with exposure risks considered as negligible (for which the monitoring protocol does not normally envisage any measurements). The absence of any retained dose following such control measurements (about one hundred control measurements carried out over a 3-month period) validates the exposure risk weighting criteria retained, as well as justifying that no measurements be carried out in the case of risks considered as negligible.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td>1</td>
</tr>
</tbody>
</table>

The articles discussed under Topic B-2-5 are applicable.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
</table>

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The feedback from unpublished professional practices shows that:
– control measurements are prescribed on a regular basis thereby allowing the non-prescription of dosimetric purpose measurements to be validated in the case of events estimated to be of a negligible level of severity.
In such a case, the validation bears on the method of the initial rating;
– when the data collected in the immediate post-event period is incomplete, this is conducive to significant-level rating and to the prescription of measurements that are sometimes useless and constraining,

The evaluation criteria for a special monitoring programme can be measured only after final committed effective dose assessment and, in some cases, are evaluated at the same time as the validity of the committed effective dose, as explained under Topic C 4.

When the initial risk rating is estimated as “intermediate” or “significant” and special monitoring is implemented, the relevance of such a monitoring programme must be examined after final dose assessment.

Three questions are raised:
1*) are the data collected following the event sufficient to calculate the dose?
2*) is the initial event rating consistent with the final dose assessment?
3*) were the measurements prescribed relevant for dose measurement?

A negative answer to any one of these three questions must entail a discussion on the relevance and adequacy of the actions carried out and propose, if possible, actions to improve and revise it.

In the absence of any negative feedback, the programme is validated.

If the initial rating of the risk yields a “negligible” value, thus leading to no special monitoring, control monitoring may be prescribed in order to confirm the relevance of the initial rating.

The elements necessary for implementing this monitoring are identical to those retained for a special monitoring programme.
The concept of a worker's internal exposure or lack of exposure to radionuclides is based on results obtained through appropriate and reliable measurements.

Radionuclides are characterized by their chemical nature and by the radiation that they emit (alpha, beta, X or gamma emitters) at different energy levels.

These measurements are carried out directly on the worker (in vivo) when the emissions of the incorporated radionuclide are not stopped by the body (which is the case with X or gamma emitters) and/or indirectly on biological samples (in vitro) for alpha, beta and gamma emitters.

Any measurement result is an indicator of exposure. Nevertheless, depending on the nature and the implementation conditions of the measurements, only some results can be retained for the dose assessment.

This chapter presents the measurements available to the occupational health practitioner within the framework of a routine or special monitoring programme, in order

– How should a measurement be chosen from among all of those available?
– What is the importance and what are the interpretation difficulties inherent to the various bioassay measurement?
– What are the analytical characteristics of the measurements according to the radionuclide measured?

The workplace air measuring techniques (individual air sample analysis) are not discussed, nor the exhaled air measurements that are not used in NIs for individual monitoring.

Q. | How do we choose a measurement from among those available?

REGULATIONS

LABOR CODE IN FORCE ON 31/12/2010 [1-1]

R 4451-62 “...When there is internal exposure, dosimetric monitoring is ensured via in vivo and in vitro measurements…”

R 4451-84 “…which the occupational health practitioner carries out or has performed”

“An order … defines the recommendations and technical instructions forwarded to the occupational health practitioner and specifies the methods for conducting special additional measurements.”

INTERNATIONAL STANDARDS AND RECOMMENDATIONS

ISO 20553 [3-1 ; 2006]

(§8.3) “- Nasal samples
- In vivo measurement
- In vitro analysis […] urine and faecal monitoring
- Exhalation monitoring: Rn-220 exhalation measurement allows the individual determination of Th-228 body burdens”


(§59) “If different methods of adequate sensitivity are available, the general order of preference in terms of accuracy of interpretation is: body activity measurements; excreta analysis; personal air sampling.”

LITERATURE REVIEW

As per the data derived from the annual IRSN report, 311,560 measurements were carried out in 2009 within the framework of routine monitoring:

– 197,901 in vivo measurements
– 49,656 urine sample analyses
– 7,130 faecal sample analyses
– 56,873 nasal mucus samples taken.

and 10,473 tests altogether within the framework of special or control monitoring, for the entire NI workers.

REVIEW ARTICLE

The 2008 article by A. Miele and al. [133 –Level of Evidence 3] is a review article on the issue raised by critical accidents. It constitutes a practical guide intended for occupational health practitioners.
A criticality accident is an uncontrolled fission reaction event. For the persons nearby, there is a sudden risk of overexposure to a mixed gamma/neutron field. Such massive irradiation causes early health effects possibly leading to death.

The Criticality Event Working Group created at the TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The measurements may have two objectives:
– A qualitative objective as an exposure indicator, to identify a contamination event and take resulting decisions stemming both from the medical and the radiation protection viewpoints.
– A quantitative objective allowing the committed effective dose to be estimated.

There are five types of bioassay measurements:
1. nasal mucus analysis
2. analysis of the saliva
3. in vivo measurements
4. faecal analysis
5. urine analysis

CEA (occupational health practitioners, biologists, dosimetric experts, researchers) has made a list of the hospital services suitable to meet with such an emergency, has codified the screening procedures and has defined the use of biological parameters that are of dosimetric interest.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3-1*-2/13* – 133</td>
<td>2* 1</td>
</tr>
</tbody>
</table>

To be exhaustive, this list is supplemented by the specific case of a criticality accident. The latter corresponds to external exposure to neutrons and, therefore, is not included in this reference. Nevertheless, it is responsible for the presence of the radionuclides detected in the blood and in the keratinous appendages (nails and hair) [133].

– a search for Na-24 (activated form of Na-23) is conducted via direct (in vivo) or indirect (blood) measurements.
– a search for P-32 (activated form of S-32) is conducted on a keratinous appendage sample (hair and nails)

The choice of laboratory measurements prescribed depends on:
– goal pursued: exposure indicator or dosimetric purposes,
– type of radiation emitted by the radionuclide,
– possibility of detecting it with an appropriate detector,
– organ in which it accumulates: in vivo measurements,
– excreta through which it is eliminated: in vitro measurements,
– time needed to conduct the measurement,
– measurement sensitivity (detection limit – interpretation limit),
– possible therapy.

When the radionuclides are known, the measurements are used as defined previously.

If the radionuclide involved is not known, it is recommended to prescribe, in the following order:
1. whole-body or organ counting
2. and on the excreta:
– X, gamma spectrometry measurements,
– beta detection measurements
– alpha detection measurements

The choice shall be refined by an investigation at the workplace.

The first-line reference laboratory is the laboratory at the site where the contamination takes place. Should it be impossible for the reference laboratory to carry out the prescribed measurements, a list of the laboratories accredited for monitoring internal exposure in application of Art. R 4451-64 of the Labor Code is available on the Nuclear Safety Authority website. A list the accredited Occupational Health Services is available on the Cofrac website.

In case of measurement difficulties, the laboratory at the site shall call on another accredited laboratory or consult with the IRSN or any other expert institutions and, if necessary, must dispatch samples for analysis.

R. 27 | How should a particular measurement be selected from among those available? (Professional agreement)
IMPORTANCE AND INTERPRETATION DIFFICULTIES INHERENT TO THE VARIOUS BIOASSAY MEASUREMENTS

Q. What is the importance and what are the interpretation-related difficulties of the different bioassay measurements?

**B-4-2-1 | Nasal mucus analysis**

In the normative literature, the term of nasal sample (NS) is generally used for nasal mucus analysis.

**INTERNATIONAL STANDARDS AND RECOMMENDATIONS**

**ISO 20553 [3-1; 2006]**

(§8.3) “Nasal samples: The analysis of nasal samples (nasal smears or nose-blowing into cellulose tissues) can supplement a special monitoring programme in order to give a rapid estimate of the severity of an event and valuable information on the nature of the inhaled contaminant. However, activity of these samples represents activity that has been removed from the body before becoming part of a systemic uptake.”

**AS PER ICRP 66 [2-7; 1994]**

The size of particles present in the nasopharyngeal cavity is for the most part of the order of 5 micrometers. However, dose assessment following inhalation is closely related to the importance of the deposit in the pulmonary alveoli region, the same being more important as the particles get smaller.

**LITERATURE REVIEW**

**CASE STUDY BASED UPON HUMAN DATA**

R. A. Guilmette' 2007 article [81 – Level of Evidence 2) is a case study analysis based upon human-data.

This is a study of the correlation between the dose and nasal sample analyses carried out over a period spanning 15 years between 1973 and 1990 at Los
Alamos National Laboratory (LANL) involving only Pu-239 (196 cases) and Pu-238 (80 cases). The LANL used water-moistened swabs for each nostril and performed the counting by liquid scintillation. Only 47 measurements were positive, both for the nasal swabs and the urine. In those cases, above the 1 Bq scintillation count, there is a linear relationship within a plus or minus 5 ratio. The uncertainty related to measuring each nostril separately yields a greater variation than through nose-blow measuring both nostrils simultaneously, which avoids anatomical variations like nasal deviations. Another factor is particle size. Other factors are: – time elapsed since the intake, which has not been taken into account despite clearance in the region – Sample quality which is dependent upon compliance to the procedure. There are some differences between this fast-evaluation method and those methods based on conventional biological samples. 2004 article by N. Blanchin and al. already quoted in A1 [22 – Level of Evidence 2] reveals the discrepancy observable between the air contamination increase level during a confinement breach event and the resulting intake value. In conclusion: – even if inhalation is subsequently confirmed, the air activity result may be lower than the detection limit, owing to the distribution in space and the radionuclide dispersion time, – the nasal mucus sample provides additional indicative data confirming inhalation. 2003 article by B. Le Guen and al. already mentioned in A1 [120 – Level of Evidence 2], supplemented by unpublished professional practices, evidences the feedback from workplaces at risk for alpha exposure at EDF. Nasal mucus samples were used as early as 1980 (unpublished practices) in addition to air contamination controls to validate the protection provided by collective and individual protection equipment, or to anticipate any air environment changes at the workplace. Furthermore, in case of positive results, such monitoring allows a contamination date to be defined in the absence of any identified event. 2002 and 2007 articles by O. Kurihara and al. [110 – Level of Evidence 3; 111 – Level of Evidence 3] bear on a case study based upon human data concerning workers exposed to plutonium compounds in Japan. 30 cases were studied between 1973 and 1999 based on nasal mucus, urine and of faeces analyses and pulmonary measurements. The first study bears on the importance of rapid conservative dose estimation from nasal samples to help decide as to the expediency of any DTPA treatment, while radio-toxicological examination of the faeces usually takes at least one week. The relationship in dose assessment obtained by each method depends on many factors. Operationally speaking and only as a conservative estimate, a 1 to 100 proportion may be retained for the faecal/nasal ratio. The second study derived from the same data sets forth action stages for the implementation of decontamination using a chelating agent, based on nasal swab test results. An equation yielding the committed effective dose according to the Pu-239, Am-241, Pu-241 composition, is provided with the different factors for MOX-using installations and reprocessing plants. 2007 study by D. Spencer and al. [163 – Level of Evidence 3] is a human data-based case analysis bearing on a study conducted on the Dounreay deconstruction site, at an unspecified time. 22 cases were followed to evidence a correlation between nasal mucus measurement results on the one hand, and urine and faeces measurement results, on the other hand. The study reveals a great variability in the relationship between intake and nasal sample results ranging 0.0047 to 107. The authors conclude that results from nasal samples should not be used to assess intake. ANALYSIS OF EXPERIMENTAL DATA 1998 article by G. Etherington and al. [63 – Level of Evidence 3] is an experimental study. The clearance of the extra thoracic liquid (ET) from the airways was measured in nine healthy volunteers for five days following inhalation of indium 111-marked polystyrene particles with aerodynamic diameters of 3 micrometers. This study has allowed: – to set forth a more realistic model for ET clearance after ICRP Publications 30 and 66, which attribute a greater deposit of 1-5 micrometer radionuclides to the ET area, as well as their impact on the dose assessment, especially for Pu-239, – to show that under certain circumstances, nose blow samples may be used to estimate intake, – that nasal mucus sample collection after an eight hour delay will yield initial activity results reduced by half.
J.R.H. Smith’s 2003 article [162 - Level of Evidence 3] adds to the previous article with the analysis of 22 additional cases with particles having aerodynamic diameters of 1.5 – 3 and 6 micrometer. Results show that the measured activity from nasal mucus samples, expressed as a percentage of the initial nasal deposit, decreases exponentially over time after inhalation.

**MEASURING METHOD**

K. Fukutsu’s 2009 article [72 – Level of Evidence 4) exposes the properties of two types of nasal swab tests used for rapid test in case of an inhaled alpha emitter. The cotton swab does not require any preparation and while it is adequate for liquid scintillation count, it is not suited for alpha counters, nor does it provide for radionuclide identification. Paper filters wrapped around sticks (flag-like) can absorb a substantial part of the alpha emission, the same increasing with paper thickness; dampening the paper with distilled water allows to maintain some of the particles at the surface and improves the counts. With this type of sample, the alpha counting yields more practical information in case of an emergency.

**TO SUMMARIZE**

The nasal sample analysis is a commonly used measurement when screening for contamination at installations at risk for actinides inhalation (alpha emitters). Several publications corroborate its value. This measurement comes in addition to:

– environmental air concentration monitoring (which can be negative owing to the distribution in space and the time for radionuclides release, while the inhalation event is subsequently confirmed),

– and the monitoring associated with other measurements which feature longer response times (see Topics B-4-3, R 33, R 34).

Under all circumstances, this estimate provides for prompt management of contaminated workers and, lastly, also for specifying the time of the contamination.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>3/1*-2/7*-2/13* 22-63-72-81-110-111-120-162-163</td>
<td>3* 3 5 1</td>
</tr>
</tbody>
</table>

**TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.**

While there is no literature reference to justify this recommendation (except for the 1998 article by G. Etherington and al. [63]), the sample must be collected as soon as possible after the end of exposure at the workplace or as soon as the news of any event has been made known in order for it to fulfil, in the best possible way, its role as an indicator of exposure. Finally, although the value of its result is particularly useful to assess the level of contamination risks, the latter cannot be used for the final dose assessment.
The nasal swab measurement is an indicator of exposure that is adapted for the alpha, beta and secondarily, gamma emitters.

This is a rapid measurement not intended for dose assessment.

The sample must be collected as soon as possible after exposure.

The activity result must specify whether it relates to the time of the measurement or to that of the sample collection and be expressed in Bq per sample.

A result less than the limit of interpretation does not allow to exclude intake via inhalation, although the probability of such occurrence is low.

“False positive” results, non-representative of inhalation, can be explained by contingent contamination (external, etc.).

The nasal swab measurement is an indicator of exposure that is adapted for the alpha, beta and secondarily, gamma emitters.

This is a rapid measurement not intended for dose assessment.

The sample must be collected as soon as possible after exposure.

The activity result must specify whether it relates to the time of the measurement or to that of the sample collection and be expressed in Bq per sample.

A result less than the limit of interpretation (R 20 - R 33) provides a good indication of the risk of inhalation.

The authors conclude as to:
– the importance of salivary sampling as an earlier indicator of exposure and an easier one to implement comparatively to urinary samples,
– the usefulness of salivary samples in assessing peak contamination level,
– the saliva-to-urine activity ratio to help determine the time of the event.

The Working Group concurs with the conclusions of J.P. Le Goff’s article (115). Furthermore, it believes that the current data does not provide for using results from salivary measurement toward intake evaluation.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>115</td>
<td>1 2 3 4</td>
</tr>
</tbody>
</table>

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The Working Group concurs with the conclusions of J.P. Le Goff’s article (115). Furthermore, it believes that the current data does not provide for using results from salivary measurement toward intake evaluation.
The geometrical configuration of the detectors is arranged to suit the purpose of the measurement, e.g. the determination of whole-body activity or of activity in a region of the body such as the thorax or the thyroid.

Total body activity will then consist of systemic activity and activity in the gastrointestinal and respiratory tracts.

"[…] body or organ content for day 1 means the content at the end of day 1 etc"

D. Franck's 2007 article [68– Level of Evidence 4] presents the different technical options toward improving internal exposure monitoring, as far as in vivo measurements is concerned:

The saliva sample is an exposure indicator that is suitable for gaseous tritium or tritiated water. This is a rapid measurement not intended for dose assessment.

The sample can be collected immediately after exposure.

The activity result must specify whether it relates to the time of the measurement or to that of the sample collection and be expressed in Bq per sample.

In the case of a positive result, the analysis must be supplemented by a radio-toxicological analysis of the urine in order to assess the dose.

REGULATIONS, SPECIFICATIONS
No regulatory reference.
3 normative references, but of no interest for the issues addressed.

INTERNATIONAL RECOMMENDATIONS
ICRP 78 [2-13 ; 1998]

(§61) "Direct measurement of body or organ content provides a quick and convenient estimate of activity in the body. It is feasible only for those radionuclides emitting radiation that can escape from the body. In principle, the technique can be used for radionuclides that emit: X or gamma radiation; positrons; […] energetic beta particles […] ; some alpha-emitters that can be detected by measurements of the characteristic X rays."

(§62) "The geometrical configuration of the detectors is arranged to suit the purpose of the measurement, e.g. the determination of whole-body activity or of activity in a region of the body such as the thorax or the thyroid."

(§63) "Total body activity will then consist of systemic activity and activity in the gastrointestinal and respiratory tracts."

(§97) "[…] body or organ content for day 1 means the content at the end of day 1 etc"

LITERATURE REVIEW

CASE STUDY BASED UPON HUMAN DATA
The 1993 article by C. Chevalier and al. [39 – Level of Evidence 3] is a case study based upon human data bearing on 5 contamination cases occurring at EDF plants and meeting the following two criteria: one total faecal activity measurement result greater than 97% as initially measured in vivo, and residual activity as measured in vivo less than 1% the initial activity. The observation period is not specified. This case is interpreted based on the fact that the inhaled particle size is markedly greater than 1 micrometer or even 5 micrometer. The inhaled particles are predominantly deposited at the upper airway level, secondarily becoming identical to indirect ingestion matter that is promptly eliminated in the excreta.

The other publications concern the measuring methods.
The use of large detecting devices placed inside shielded rooms that are required to prevent interference from background noise from the environment or electronic chains, helps identify the radionuclides concerned, as well as quantifying the activity thereof after calibration with anthropomorphic phantoms. Biokinetic models allow the target organ to be identified and the detector to be placed accordingly. Many elements are uniformly distributed within the body and the measurements are therefore whole-body counting. To that end, most installations use fixed detection systems. One special feature of the Saclay Biological Analyses laboratory is the use of the detector’s scanning function during the measurement, in order to spot the activity within isolated tissues and organs like the thyroid, the lungs, bones, the liver, etc. The authors present experimental feedback from such an installation used on a few typical cases in search of radioelements during monitoring of fuel-cycle workers, as well as possible applications in the medical field. The value of precise activity localization at the whole-body level and of laboratory spectrometric urinary measurements is to better identify exposure, monitor work conditions and refine the kinetic knowledge of the material handled.

REVIEW ARTICLE

P. Bérard’s 2003 article [6 – Level of Evidence 4] is a review article pertaining to in vivo measurements. In vivo measurements consists in determining the intake by detecting, outside the body, any decay-associated X and gamma rays emitted thereby. These ISO-defined analyses measure the radionuclide inside the human body using instruments capable of detecting the radiation emitted by that radionuclide within the body (in vivo). In fact, in vivo measurement provides for determining the entire activity present in the body at a given time, so as to retrace initial intake.

TO SUMMARIZE

The in vivo measurement is suitable for X or gamma radiations from the incorporated radioelements regardless of the initial route of entry. It is not adapted to radionuclides that emit only low-energy alpha or beta radiations, which are stopped by the body.

For this measurement to be interpretable, it must be obtained so as to overcome the interference of any external contamination or from the clothes.

This measurement can be carried out on the body as a whole or targeted on an organ, depending on the radionuclide’s distribution (e.g. thyroid or lung).

The activity measured just after an incident, especially when the lungs are involved, can correspond to a superimposition of the lungs’ incorporated activity and of that of the digestive tract and bronchi, thus leading to an overrated pulmonary intake test.

The sensitivity and specificity of the measurement depend on the equipment used.

The time of the measurement is the time act which commence the in vivo measurements.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2/13* – 2-6-39-68-93</td>
<td>1* 1 4</td>
</tr>
</tbody>
</table>
The in vivo measurement is an indicator of exposure adapted to gamma- and X-emitters.

This is a fast-response measurement aimed at dose assessment. The measurement may concern the whole body or a particular organ: thyroid, lung, etc.

The examination must be carried out as soon as possible following the exposure.

The activity result relates to the time of the measurement and is expressed in Bq.

False positive results, not representative of intake, can be explained by residual external contamination of the skin or garments.

A positive result for measurements obtained during the first three days may be representative of ingestion or inhalation (respiratory fraction eliminated by the digestive tract especially when large particles are involved).

The in vivo measurement is an indicator of exposure adapted to gamma- and X-emitters. It is a fast-response measurement aimed at dose assessment. The measurement may concern the whole body or a particular organ: thyroid, lung, etc.

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False positive results, not representative of intake, can be explained by residual external contamination of the skin or garments.

A positive result for measurements obtained during the first three days may be representative of ingestion or inhalation (respiratory fraction eliminated by the digestive tract especially when large particles are involved).

**INTERNATIONAL STANDARDS AND RECOMMENDATIONS**

**ISO 20553 [3-1; 2006]**

§(8.3) “Large fluctuations in the faecal excretion of radionuclides from one day to the next […] Consequently, faecal samples should preferably be collected over a period of about three days […] Faecal samples collected soon after intake include non-systemic activity from lung clearance to the GI tract or directly from ingestion.”

**ICRP 78 [2-13; 1998]**

§(70) “The analysis of faecal samples for routine monitoring involves uncertainty in interpretation owing to daily fluctuations in faecal excretion. Ideally, therefore, collection should be over a period of several days. However, this may be difficult to achieve in practice and interpretation may need to be based on a single sample. Faecal monitoring is more often used in special investigations, particularly following a known or suspected intake by inhalation of Type M or S compounds.”

§(97) “For excreted activities, the value at day 1 represents the activity excreted during the first day after intake, corrected for radioactive decay to the end of day 1.”

**ICRP 23 [2-1; 1975]**

ICRP 23 specifies that for adults the weight of ash is 17 g/d and 15 g/d for males and females, respectively. However, there is no conformity criterion for the weight of faeces per 24 hours.

**LITERATURE REVIEW**

**CASE STUDY ANALYSIS BASED UPON HUMAN DATA**

The 2007 article by L. Julio and al. [104 – Level of Evidence 2] is a case study based upon human data presenting results from 205 faecal bioassay measurements conducted in a systematic uranium exposure monitoring setting over an unspecified period of time, on 154 workers from a fuel manufacturing company.

The study involved the search for U-234 in 205 faecal samples collected from among 154 workers and analysed either separately, in the case of 133 samples, or over 3 days, including 21 that were tested over 3 consecutive days and 3 that were tested over 3 non consecutive days. The faecal mass and composition vary according to many factors, including diet and intestinal transit time. From one day to the next, the faecal mass may vary of a 1.3 to 5.7 ratio, thereby causing a 1 to 30 variation ratio in U-234 from one day to the next (in 1 case, the variation ratio may reach 1 to 40). The authors conclude that:
The parameters examined were those impacting dose assessment based on bioassay measurements of faeces. It is important to take into account:
- the influence of the isolated, repeated or chronic character of the intake over the monitoring period,
- the route of entry: inhalation or ingestion,
- the variation resulting from analysing a single faeces sample.

As a result:
- measurements vary according to the weight of the collected faeces,
- it is recommended to collect 3 faecal samples.

METHODOLOGICAL APPROACH
The 2007 article by D. Bingham and al. [13; Level of Evidence 4] presents an approach concerning the result analysis of routine monitoring measurements obtained from 130 people from 2003 to 2006, following exposure to Pu-238, Pu-239 and Pu-240.

One-day sample collection is not appropriate for dose assessment and the authors recommend taking samples over 3 to 4 days, to reduce the variability of the results found.

Analysis of the faeces is particularly well-adapted to the monitoring of insoluble compounds, which usually are not detectable through bioassay measurement applied to urine.

As a result:
- faeces evolves markedly according to the daily fluctuation in the amount of stool in the same individual. It is therefore recommended to carry out this analysis over 3 consecutive days.

Regarding samples collected during the first 10 days after the incident, measurements will be carried out on each 24-hour sample and every result will be interpreted.

For dose assessment purposes, the ICRP recommends for 24-h samples that the date of the end of the sample collection be retained as a reference.

RESULTS FROM BIOASSAY MEASUREMENTS PERFORMED ON FAECES

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3/1*-2/1*-2/13* – 13-104</td>
<td>3* 1 1</td>
</tr>
</tbody>
</table>

REGARDING PROFESSIONAL PRACTICES, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

Regarding the result processing method, the WG makes some additional comments drawn from the feedback on unpublished professional practices.

A knowledge of the laboratory coding method for sample dating is mandatory.

As concerns samples collected later than 10 days subsequent to an incident, i.e., during the plateau elimination phase, or within the framework of routine monitoring, sample collection concerns a 72-hr period. In this case, however, it is possible to use as a 24-hr unit result the geometric mean of the 3 24-hr analyses.

\[
\sqrt[3]{\text{measure 1} \times \text{measure 2} \times \text{measure 3}}
\]
### Analysis of faeces

1. **What does the measurement accomplish?**
2. **What are the sample compliance criteria?**
3. **What are the interpretation limits of the results?**

### REGULATIONS

**GRADE B**

The bioassay analysis of the faeces is an indicator of exposure adapted to alpha and gamma emitters.

This is a delayed-response measurement with dosimetric purpose.

In the case of an event, the sample must be collected rapidly, preferably over 3 consecutive days.

The activity results relates to the time at the end of the sample collection period, and is expressed in Bq per sample.

Any result greater than the derived recording level (DRL; R 43-44) must be controlled after exclusion.

**PROFESSIONAL AGREEMENT**

The conformity criterion for a 24-hr faecal sample is based on the ash weight, which should be at least 1 g / 24 h.

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### INTERNATIONAL STANDARDS AND RECOMMENDATIONS

- **ISO 20553 [3-1; 2006]**
  - (§8.3) “Usually, a reliable dose assessment on the basis of urinary analysis requires a 24 h sample; but in the case of special monitoring programmes, it can be helpful to collect “spot samples”.”

- **ICRP 78 [2-13; 1998]**
  - (§69) “The collection of urine samples involves three considerations. Firstly, care must be taken to avoid adventitious contamination of the sample. Secondly, it is usually necessary to assess the total activity excreted in urine per unit time from the sample provided. For most routine analyses, a 24 h collection is preferred but, if this is not feasible, it must be recognised that smaller samples may not be representative. Tritium is a particular case for which it is usual to take only a small sample and to relate the measured activity concentration to the concentration in body water. Thirdly, the volume required for analysis depends upon the sensitivity of the analytical technique. For some radionuclides, adequate sensitivity can be achieved only by analysis of several days’ excreta.”

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### LITERATURE REVIEW

The different publications concern the measurement methods.

**MEASUREMENT METHOD**

2007 article by A. Andrasi and al. [2 – Level of Evidence 4] exposes the broad lines of the IDEA project concerning the internal dosimetry test and its advantages as compared to conventional methods. One way of development concerns the use of mass spectrometry for alpha-emitting radionuclides during systematic monitoring, particularly when testing for thorium and uranium. This method proves faster, simpler and less costly.

D. Franck’s 2007 article, already quoted [68 – Level of Evidence 4] presents the different technical possibilities for improving monitoring for internal exposures using biological samples via:

- faster and higher extraction of the radionuclides sought using host-guest molecules like calixarenes.
- early identification of long-life radionuclides by a mass spectrometry (ICP-MS)

Finally, the use of such methods could change the monitoring protocols.

2006 article by N. L. Eliott and al. [61 – Level of Evidence 4] presents the results obtained by thermal ionizing mass spectrometry (TIMS) that enables to detect quantities of the order of the femtogram, as regards Pu-239 and Pu-240 in urinary samples. An annual measurement provides for detecting an inhalation committed effective dose of the order of 0.1 to 1 mSv as concerns most chemical forms of plutonium, which corresponds to sensitivity requirements encountered in the nuclear industry in terms of routine monitoring.

2006 article by I. Giardina and al. [73 – Level of Evidence 4] is an article that provides details on measuring techniques of no concern to the issues addressed here.
TO SUMMARIZE

Urine analysis provides for measuring alpha, beta or gamma emissions. The presence of any radionuclide in the urine is absorption-dependent. This can be used in case of an incident or in routine monitoring. This is a measurement suitable for dose assessment. Detection of alpha emitters requires chemical treatment prior to counting, and results cannot be expected earlier than 7 to 10 days.

The sample must be collected continuously over 24 hours.

For dose assessment needs, the ICRP recommends using as an end point time for 24-hr samples the time of the end of the sample collection period.

REGARDING THE PROFESSIONAL PRACTICES, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The WG makes some additional comments drawn from the feedback on professional practices.

DTPA processing dictates a specific sample collection procedure.

As concerns special monitoring, the sample must be collected over 24 hours consecutively.

As concerns routine monitoring and to foster sample acceptability, the same must be collected divided over 3 to 5 consecutive days until a total volume of at least one litre is obtained.

TO SUMMARIZE

Bioassay analysis of the urine is an indicator of exposure adapted to alpha, beta and gamma emitters.

This is a delayed-response measurement with dosimetric purpose.

The sample is collected either over 24 hours, or from one spot sample in the following particular cases:

– concerning tritium: previous emptying of the bladder, then sample collection at least 2 hours post exposure
– concerning uranium-derived soluble compounds, immediate urine sample collection.

The activity result relate to the time of the sample collection period and is expressed in Bq per sample or in Bq per litre.

The treatment received by the worker must be specified on the measurement prescription, since this may have an impact on the technique used by the laboratory.

The compliance criteria for 24-hr urine sample collection are:

– minimum urine volume of 500 mL
– creatininuria greater than or equal to 0.5 g/l

Any positive urine analysis can be related to contingent sample contamination (in particular by external contamination transfer through the hands).

Any result greater than the derived recording level (DRL; R 43-44) must be controlled after exclusion.
OPERATIONAL INTERPRETATION LIMIT previously defined with the prescribing health practitioner. This operational interpretation limit is higher than the analytical detection limit. It is established with the aim of optimizing response time.

Regarding fast-response measurements which are not used for dose assessment, the laboratory report, instead of being expressed in terms of activity, can be expressed literally as “negative” or “positive” with respect to the detection limit or to an operational limit defined beforehand with the prescribing health practitioner.

The list of measurements was dressed up based on the most frequently encountered radionuclides, taking into account the feedback from the overall NI activity values (see Limits of the recommendations and Topic C-2-2).

### REGULATIONS, INTERNATIONAL STANDARDS AND RECOMMENDATIONS

No reference

### LITERATURE REVIEW

No reference

### REGARDING THE PROFESSIONAL PRACTICES, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

Tables (R 33 and 34) were drawn up based on the professional practices of the biomedical laboratories and the Occupational Health Service.

The performance and time delays indicated depend on the measurement principles used.

The LIMITS OF DETECTION of the tests are closely related to the time delays within which the test is carried out, as well as to the technical characteristics. These comply with the usual values indicated in the ICRP Publications 54 [2-4] and 78 [2-7] and with the ISO 12790. [3-3] standard.

As was already recalled under Topic B-3-3, for some measurements or to suit certain particular situations (important number of persons being contaminated), the laboratory can yield results starting from an

### TABLE N°2. EXPOSURE INDICATORS WITH THEIR MEASUREMENT CHARACTERISTICS.

<table>
<thead>
<tr>
<th>TYPE OF ANALYSIS</th>
<th>SUBSTRATE</th>
<th>ANALYTICAL TECHNIQUE</th>
<th>INDICATIVE EXECUTION TIME</th>
<th>LIMITS OF INTERPRETATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>alpha, beta, gamma emitters</td>
<td>nasal mucus nasal sample or flag-papers</td>
<td>Overall direct count</td>
<td>15 min - 1hr</td>
<td>alpha 0.7 Bq beta 7 Bq gamma 2 Bq</td>
</tr>
<tr>
<td>alpha, beta, gamma emitters</td>
<td>nasal mucus paper tissue</td>
<td>Calcination + overall direct count</td>
<td>2hrs</td>
<td>100 mBq / sample</td>
</tr>
<tr>
<td>alpha emitters</td>
<td>faeces thick layer</td>
<td>Calcination + overall direct count</td>
<td>&lt;24-hr</td>
<td>0.2 Bq per g of ash</td>
</tr>
<tr>
<td>tritium</td>
<td>saliva saliva wipes</td>
<td>Direct liquid scintillation method</td>
<td>&lt; 6 hrs</td>
<td>0.3 kBq</td>
</tr>
<tr>
<td>X or gamma emitters</td>
<td>localized spectrometry</td>
<td>Direct method</td>
<td>&lt; 1 hr</td>
<td></td>
</tr>
</tbody>
</table>
TABLE N°3. INDIVIDUAL MONITORING MEASUREMENTS WITH THEIR ANALYTIC CHARACTERISTICS.

<table>
<thead>
<tr>
<th>TYPE OF ANALYSIS</th>
<th>SUBSTRATE</th>
<th>ANALYTICAL TECHNIQUE</th>
<th>INDICATIVE EXECUTION TIME AFTER COLLECTION</th>
<th>DETECTION LIMIT</th>
<th>DETAIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha emitters</td>
<td>24-hr faeces</td>
<td>Separative method with tracer + alpha spectrometry</td>
<td>1 week to 10 days</td>
<td>1 mBq</td>
<td>0.2 to 0.5 mBq</td>
</tr>
<tr>
<td>Pu / Am / Cm</td>
<td>24-hr urine</td>
<td>Separative method with tracer + alpha spectrometry</td>
<td>1 week to 10 days</td>
<td>1 mBq</td>
<td>0.2 to 0.5 mBq</td>
</tr>
<tr>
<td>Alpha emitters</td>
<td>24-hr faeces</td>
<td>Separative method with tracer + alpha spectrometry</td>
<td>1 week to 10 days</td>
<td>1 mBq</td>
<td>0.2 to 0.5 mBq</td>
</tr>
<tr>
<td>U / Th</td>
<td>24-hr urine</td>
<td>Separative method with tracer + alpha spectrometry</td>
<td>1 week to 10 days</td>
<td>1 mBq</td>
<td>0.2 to 0.5 mBq</td>
</tr>
<tr>
<td>Uranium</td>
<td>Urine (spot sample or 24-hr sample)</td>
<td>Mass spectroscopy</td>
<td>3 hrs</td>
<td>0.1 - 4 microgram/L</td>
<td></td>
</tr>
<tr>
<td>Beta emitters</td>
<td>Urine</td>
<td>Direct liquid scintillation method</td>
<td>2 hrs</td>
<td>50 Bq/L</td>
<td></td>
</tr>
<tr>
<td>Type H-3, C-14, Nor-63</td>
<td></td>
<td>Separative method + liquid scintillation</td>
<td>24-48 h</td>
<td>5 Bq/L</td>
<td></td>
</tr>
<tr>
<td>Beta emitters</td>
<td>Urine (spot sample or 24-hr)</td>
<td>Separative method + Liquid scintillation or proportional counter</td>
<td>48 hrs</td>
<td>0.2 – 0.8 Bq/L</td>
<td></td>
</tr>
<tr>
<td>Type P-32, S-35, Cl-36, Ca-45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta emitters</td>
<td>Keratinous appendages (nails, hair)</td>
<td>Separative method Direct measurement + liquid scintillation</td>
<td>24 hrs</td>
<td>0.1 Bq/g</td>
<td></td>
</tr>
<tr>
<td>Type Sr-90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta emitter</td>
<td>24-hr faeces</td>
<td>Liquid scintillation</td>
<td>24 hrs</td>
<td>10 Bq</td>
<td></td>
</tr>
<tr>
<td>Type Pu-241</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma emitters</td>
<td>Whole body</td>
<td>in vivo counting</td>
<td>&lt; 1 hr</td>
<td>Cs-137: 50-150 Bq</td>
<td></td>
</tr>
<tr>
<td>&gt; 200 keV</td>
<td>24-hr urine</td>
<td>Direct spectrometry</td>
<td>&lt; 3 hrs</td>
<td>Cs-137: 0.2-2 Bq/L</td>
<td></td>
</tr>
<tr>
<td>Blood</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma emitters</td>
<td>24-hr faeces</td>
<td>calcination Direct spectrometry</td>
<td>24 hrs</td>
<td>1 Bq/sample</td>
<td></td>
</tr>
<tr>
<td>All energies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma emitters</td>
<td>Whole body</td>
<td>in vivo counting</td>
<td>&lt; 1 hr</td>
<td>I-125, I-129 10-20 Bq</td>
<td></td>
</tr>
<tr>
<td>-X ≤ 200 keV</td>
<td>24-hr urine</td>
<td>Direct spectrometry</td>
<td>&lt; 3 hrs</td>
<td>I-125, I-129 1-2 Bq/L</td>
<td></td>
</tr>
<tr>
<td>Lungs</td>
<td>in vivo localized counting</td>
<td>&lt; 1 hr</td>
<td>Am-241: 8-20 Bq Pu-239 &gt; 3000 Bq U-235: 3-27 Bq</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thyroid</td>
<td>In vivo localized counting</td>
<td>&lt; 1 hr</td>
<td>I-131: 3-10 Bq</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Analytical LD = approximate values or value ranges provided by the laboratories.
2 In case of DTPA processing, the technique recommended is wet mineralization in order to destroy the Pu-DTPA or Am-DTPA complex.
3 the conversion of the mass activity result (Bq) depends on the isotopic composition of the product.
4 varies according to the subject’s chest thickness.
Q. What impact do social-economic elements have on the monitoring programme?

REGULATIONS, INTERNATIONAL STANDARDS AND RECOMMENDATIONS
No reference

LITERATURE REVIEW
CASE STUDY ANALYSIS BASED UPON HUMAN DATA
2005 article by N. Blanchin and al. quoted earlier in A-1 [23 – Level of Evidence 2] describes the setting up of a new monitoring protocol introducing much more sensitive measurements (faeces) to monitor occupational exposure to the actinides, in order to meet the regulations on lowered dose limits. This change in the monitoring procedure has brought out many small contamination cases (approximately 10% of the measurements performed yielded results above the detection limit) that were not detected through former measurements (urine). These results were apt to produce substantial anxiety in the company, which could be overcome only by adequate communication, in particular with management and staff representatives.

2004 article by N. Blanchin and al. already quoted in A1 [22 – Level of Evidence 2] highlights the sensitive nature of contamination events and the difficulty for the occupational health practitioner to control prescriptions owing to the important pressure put on him/her, both on the part of his/her superiors and on the part of the employees or their representatives. Only the implementation of quite well-defined and well-argued protocols can ensure controlled management of such situations. Finally, the authors emphasize the importance of the way in which these protocols as presented at different company levels, as well as of recurrent control studies of the results.

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<tr>
<th>Note</th>
<th>Literature references</th>
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<td>2</td>
<td>22-23</td>
<td>2</td>
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REGARDING THE PROFESSIONAL PRACTICES, THE WORKING GROUP HAS RULED ON THE FOLLOWING ISSUES AND MAKES THE FOLLOWING RECOMMENDATIONS.

The feedback on professional practices shows that the social-economic aspects should not be overlooked, both as far as the workers as concerned and the employers as well as other parties of interest.

There is an effort to be made in terms of communication and pedagogy to explain and justify the constraints set forth by the monitoring. Acceptance and an understanding of those constraints will best ensure heeding of all of the parties involved and improved compliance with the prescriptions on the part of workers. Acceptance is particularly important where routine monitoring is concerned.
R. 35 | What impact do social-economic elements have on the monitoring programme? (Professional agreement)

<table>
<thead>
<tr>
<th>Constraints generated by the storage of the excreta samples: accessibility to the place of sample collection, the time schedule for possible storage (especially for workers in post), organization and planning of the measurements in cases when workers are away on long-term missions, traveling abroad, or when they are itinerant.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A monitoring programme must find the right balance between the health benefit expected and acceptability both for the workers and for the employer.</td>
</tr>
<tr>
<td>To best ensure heeding on the workforce’s part, the monitoring programme must prioritize:</td>
</tr>
<tr>
<td>– measurements that feature the longest monitoring intervals in order to limit the numbers thereof. For an equivalent interval, the test that enjoys better acceptance should be preferred.</td>
</tr>
<tr>
<td>– appropriate communication regarding the justification of the monitoring and the importance of submitting to it. Such communication should be renewed on a regular basis.</td>
</tr>
<tr>
<td>Exceptionally, in the absence of any objective element permitting to question the monitoring programme defined, certain measurements can be prescribed outside the programmes per se to reassure a worker.</td>
</tr>
<tr>
<td>Acceptability for the employer is closely related to the cost rationale, including the following aspects:</td>
</tr>
<tr>
<td>– relevance of the monitoring,</td>
</tr>
<tr>
<td>– nature and the frequency of the measurements,</td>
</tr>
<tr>
<td>– impact of such measurements on work organization, particularly if this should involve excluding risks for the workers.</td>
</tr>
<tr>
<td>Acceptability for the persons concerned, and hence compliance with the measurements depend on:</td>
</tr>
<tr>
<td>– nature of measurement or measurements:</td>
</tr>
<tr>
<td>– faecal sample collection is normally harder to accept than urine sampling,</td>
</tr>
<tr>
<td>– the sample collection equipment must be convenient to use,</td>
</tr>
<tr>
<td>– frequency: the more frequent the measurements, the greater the chance that the persons implicated refuse or neglect submitting to such,</td>
</tr>
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</tr>
<tr>
<td>– relevance of the monitoring,</td>
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<tr>
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</tr>
<tr>
<td>– the sample collection equipment must be convenient to use,</td>
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<tr>
<td>– frequency: the more frequent the measurements, the greater the chance that the persons implicated refuse or neglect submitting to such,</td>
</tr>
</tbody>
</table>

What impact do social-economic elements have on the monitoring programme? (Professional agreement)
T O - P I C C.
DOSE ASSESSMENT BASED ON MEASUREMENTS

In principle, the assessment of an intake of a radionuclide and the associated committed effective dose on the basis of in vivo measurements and excreta analyses is simple.

However, the integration of several individual measurement results, prescribed as part of an individual monitoring protocol, can rapidly make this task more complex. It is difficult to validate activity intake and committed effective dose assessments owing to the number of variables and their associated uncertainties, as confirmed by the results of intercomparison exercises (Andrasi and al 2007 [2] and Doerfel and al 2000 [57]) whose analysis is mentioned in Topic C-4.

We note that very often the assessed dose values do not necessitate further investigations (later surveys and tests) or assessments (review of the hypotheses), as attested by the IRSN annual reports [101].

This chapter looks at the interpretation of excreta analysis results to assess the committed effective dose in different situations (routine or following a particular event).

It responds to the main questions of occupational health practitioners in NIs:
- Which default models and parameter values should be used?
- Which method should be used to interpret the first measurement results rapidly?
- How do we evaluate the intake and committed effective dose?
- When do we validate the assessment of committed effective dose?
- How do we exploit the measurement results?
- How do we handle the special case of a contaminated wound?
- How do we validate a dose assessment and what should we do when faced with inconsistencies?
- What can we say about the uncertainty in the dose assessment?
- What can we expect from dose assessment software?
- Are there alternatives to use of the default model?

C-1 | WHICH DEFAULT MODELS AND PARAMETER VALUES SHOULD BE USED?

This section replies to the following questions:
Which model should be used by default?
Which default parameters should be associated with the model?
- for data relating to monitoring: methods (intervals, mode) and time of intake,
- or data relating to the characterization of the contaminant compound or mixture: absorption type, particle size, compound type, etc.,
REGULATIONS

LABOR CODE IN FORCE ON 31/12/2010 [1-1]
[R 4451-16] “The methods of calculating effective dose and equivalent doses are defined by a decision of the Nuclear Safety Authority approved by the Ministers of Employment and Agriculture. In the special case of nuclear activities defined in 1° of Article R 4451-1, and when knowledge of the exposure parameters allows a more precise assessment, other methods can be used, provided these are accepted by a decision of the Nuclear Safety Authority approved by the Ministers of Employment and Agriculture and that they have been submitted for opinion to the Health, Safety and Working Conditions Committee ("CHSCT") or, otherwise, to staff representatives.”

DECREE DATED 1 SEPTEMBER 2003 [1-2]
This defines the methods of calculating the effective dose resulting from internal to radionuclides exposure.
Appendix III gives the values of the dose per unit intake (OPUI, h(g) values of table III) in Sv/Bq taken from the transposition of the European Directive 96/29/Euratom.

INTERNATIONAL RECOMMENDATIONS

ICRP 103 [2-17; 2007]
(§B171) “The system of dose assessment for intakes of radionuclides that is generally applied relies first on the calculation of the intake of a radionuclide either from direct measurements (e.g., measuring the radioactivity of the whole body by whole body counter or of specific organs and tissues by external counting devices) or indirect measurements (e.g., measuring the radioactivity in urine, faeces, air or other environmental samples). Biokinetic models have to be applied and the effective dose is calculated from the intake using reference dose coefficients (doses per unit intake, Sv Bq-1) recommended by the Commission, and also reproduced in the EU Basic Safety Standards Directive (EU, 1996) and in the International Basic Safety Standards (IAEA, 1996). The Commission has provided dose coefficients for intakes by inhalation and ingestion for a large number of radionuclides, relating the intake of a specific radionuclide to the corresponding organ and effective dose committed within a specified period (ICRP, 1994b, 1996c). Dose coefficients have been given for members of the public and for adults who are occupationally exposed.”

EUROPEAN WORKING GROUP REPORTS

IDEAS GUIDELINES [56; 2006] LEVEL OF EVIDENCE 2
The IDEAS Guidelines propose a method for assessing the committed effective dose on the basis of monitoring data.
They give general guidelines in a three-step procedure according to the expected level of exposure:
– Level 1: the assessment is performed using default or site-specific parameters values.
– Level 2: the values of the individual adjustment parameters are applied.
– Level 3: a special assessment is conducted with individual adjustment of the model’s parameter values.

LITERATURE REVIEW
The literature search found little to orient the choice of the default model.
The publications found concern human data, for which using the default model (with the parameter values) raises problems of inconsistency between the different assessments. These publications are analysed in Topic C-4-2.
AUTHOR’S OPINION
The article by W. Blommaert and al in 1997, already cited in B1 [25 – Level of Evidence 4] illustrates the method proposed by the IDEAS Guidelines. The article underlines in particular the complexity of assigning doses on the basis of bioassay data. The objective is not to perform a fundamental study of dosimetry models as such, but to express the viewpoint of health professionals confronted with interpretation problems, such as the consequences of radionuclide intake.

This article confirms the importance of having data about the workplace and working situations; it does not call into question the three-step method.

TO SUMMARIZE
To assess the committed effective dose, the regulatory framework refers to the biokinetic and dosimetric models of ICRP publications. These are established for a so-called “Reference Man” [ICRP Publication 89].

The choice and use of these models presupposes the availability of information about the circumstances of exposure and the nature of the contaminant product or mixture.

In the absence of this information, default choices must be made.

The term “default” is employed in the sense of a standard value to use in first intention in the absence of specific information.

In some cases, the use of the default model and values does not yield a consistent estimation of intake, so other hypotheses must be envisaged. These situations will be mentioned in Subject C-4.

<table>
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<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
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<tbody>
<tr>
<td>5</td>
<td>2/6*-2/13*-2/17* – 25-56</td>
<td>3* 1 1</td>
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</table>

The models to use by default are those published by the ICRP.

For the main radionuclides present in NIs, ICRP Publication 78 describes the excretion and retention functions enabling exploitation of bioassay measurements to assess intake then committed effective dose.

Usage conditions of the models:
- expression of the measured or estimated quantities as global activity: Bq (disintegrations per second)
- expression of time in days, with excreted quantities expressed in Bq/24h
Consequently, the recommendations mainly concern exposure resulting from contamination following a single occasional event (acute intake) by inhalation. Problems specific to the other exposure modes are dealt with in:

ISO 27048 [3-2; 2011]  
§7.1.3 “Note: an assumption of a chronic and constant intake rate might better represent constant intake probabilities and result in unbiased estimates. Nevertheless, the assumption of an acute intake event is chosen here for reasons of consistency with ICRP recommendations.”

ICRP 78 [2-13; 1998]  
§20 “The respiratory tract, the gastro-intestinal tract, the intact skin, and wounds are the principal routes of entry to the body.”  
§22 “The models for the major routes of intake (inhalation and ingestion) are described in the following Sections. For some radionuclides, it is also necessary to consider direct uptake from contamination on the skin. […] Generally, radionuclides do not cross the intact skin to any significant extent. […] the most important is tritiated water and this is the only case considered in this report.”  
§100 “For routine monitoring, only intake by inhalation is considered.”  
§101 “Finally, some information is also given on the build-up of activity […] for the hypothetical case of continuous daily intake by inhalation […] These data cannot be used directly to evaluate intakes and doses in any particular monitoring period. They may, however, be useful […] in situations where workers are unlikely to be exposed to significant intakes of radionuclides, comparison of the results of occasional screening measurements with these data may provide reassurance that intakes are indeed low.”

EUROPEAN WORKING GROUP REPORTS  
IDEAS GUIDELINES [56; 2006] LEVEL OF EVIDENCE 2  
The guidelines propose a practical approach to identify the intake route:  
– either it is obviously by inhalation alone, due for example to air contamination at the workplace without external contamination of the worker,  
– or it is obviously by ingestion alone, due for example to contamination of the worker without air contamination at the workplace,  
– or a combination of inhalation and ingestion, due for example to contamination of the worker plus air contamination at the workplace,  
– or contamination by injection or percutaneous.  

However, it concludes that if no data enable the respective ingestion part to be determined, or if the origin of the absorption cannot be identified, the inhalation route is used exclusively.

LITERATURE REVIEW  
No references

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<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
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<tr>
<td>3</td>
<td>3/2* - 2/13* – 56</td>
<td>2* 1</td>
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TO CONCLUDE  
Experience within the WG of professional practices enables us to confirm that in usual working situations, the principal intake mode for workers is inhalation following dispersion of radioactive particles in the air due to a single event. Consequently, the recommendations mainly concern exposure resulting from contamination following a single occasional event (acute intake) by inhalation. Problems specific to the other exposure modes are dealt with in:
The article by A. Birchall and al in 2007 [18 – Level of Evidence 4] confirms the results of Puncher and al [152] by taking into account measurement uncertainties. It quantifies the bias introduced by the different hypotheses.

The article by G. Wilson and al in 2007 [173 – Level of Evidence 4] is a study of dose assessment sensitivity, in the case of exposure to plutonium and based on urinary measurements generated artificially, to errors in the dose calculation parameters (intake frequency, scattering factor (see C-4-4), particle size, absorption type). The hypothesis of constant chronic intake is found to yield robust results, except when the absorption type is erroneous.

The article by A. Molokanov and al in 2007 [137– Level of Evidence 4] studies the influence of the intake frequency on the evaluation of intake in routine monitoring in the example of contamination.

Note: the Decree dated the 1st of September 2003 on dose calculation provides only dose coefficients for intake by inhalation and ingestion.
The article by D.J. Strom in 2003 [165 – Level of Evidence 4] is an author’s opinion. It expresses his disagreement with the ICRP recommendation. If the probability of occurrence of an intake is uniform over time, the recommendation made in ICRP Publication 78 to use the middle of the interval leads to a bias in the average estimates of incorporated activity and dose. This bias is largest for radionuclides of short life relative to the monitoring interval. The author suggests that the ICRP should review its recommendations.

TO SUMMARIZE
Generally, the excretion and retention functions (ICRP Publication 78) corresponding to the measured quantities decrease with the time since intake.

ICRP Publication 78 [2-13] and ISO 20553 [3-1] standard propose to make in first intention the assumption of intake in middle of the monitoring interval, which guarantees a maximum factor of 3 in the underestimation (lower limit) and the overestimation (upper limit). Note that the respect of the maximum factor 3 in the overestimation of an intake can be checked only if the radiotoxicological sampling is conducted after a period of exclusion of the subject from his workplace.

Further, when the intake time is unknown:
– assuming a time more recent than the real time leads to an underestimated intake,
– assuming a time earlier than the real time leads to an overestimated intake.

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<tr>
<td>8</td>
<td>3/1*-2/13*-2/35* – 18-137-152-165-173</td>
<td>3*</td>
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</table>

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.
The analysis of professional practices (unpublished) reveals that the assumption of intake in the middle of the interval is rarely used to interpret the routine monitoring data. Occupational health practitioners in first intention tend to interpret results by assuming that an intake occurred on the day after the previous measurement (start of the interval), in other words they make the most disadvantageous assumption.

The WG proposes a comparison of the advantages and disadvantages of each of the hypotheses:
R. 38 | Which default intake time should be used? (Professional agreement)

If the event is identified, the intake time is the time of the event.

If the event is unidentified:
– **As a first approximation**, to decide the prescription of control measurements based on the first results, the chosen intake time is the first day of the monitoring interval.

– Then, to assess the dose, according to the measurement results and the investigation:
  – the chosen intake time will be the most plausible date.
  – if no information is available to determine the intake time, the time chosen will be the **middle of the interval**, in accordance with international recommendations.

Q. C-1-4 | Which default absorption type and particle size should be used?

REGULATIONS
**DECREES OF THE 1ST OF SEPTEMBER 2003 [1-2]**

Tables 1.3, 3.2 and 3.3 show the absorption type to use for each element, according to its chemical form.

For the choice of the particle size value, Appendix III-2 states:

“For intake by inhalation of aerosols, the values of dose per unit intake in table 3.1 are given for two values of activity median aerodynamic diameter of the inhaled particles: 1 and 5 micrometers. If there is data for this parameter, the corresponding value must be used, otherwise the value corresponding to 5 micrometers will be used by default.”

INTERNATIONAL RECOMMENDATIONS
**ICRP 78 [2-13; 1998]**

This publication proposes for each radionuclide and inhalation route:
– Three types of absorption according to the biological period of absorption from the alveolar compartment to the systemic compartment:
  – Type F (Fast)
  – Type M (Moderate)
  – Type S (Slow)

The chemical form of the radionuclide determines the choice of the type.

– Two dose coefficients according to the particle size: 1 and 5 micrometers.

§25 “For occupational exposure the default value now recommended for the Activity Median Aerodynamic Diameter (AMAD) is 5 micrometers (Publication 68) which is considered to be more representative of workplace aerosols than the 1 micrometer default value adopted in Publication 30.”

**ACCORDING TO ICRP PUBLICATION 66 [2-7; 1994]**

The choice of the particle size directly influences the intake assessment, via the fraction of inhaled activity deposited in the respiratory tract; see Topic B-4-2.

Most fine particles (diameter less than about 1 micrometer) are deposited deep in the lungs, close to the pulmonary alveoli, and contribute significantly to the dose.

Insoluble particles of larger diameter (notably above 10 micrometers) are, depending on the mechanical clearing of the lungs and extrathoracic airways, secondarily oriented to the tracheo-oesophagean crossroads (so-called indirect secondary ingestion), and are then faecally excreted; they contribute little to the dose.
– The median is 6.8 micrometers (but with AMADs frequently exceeding 10 micrometers) in uranium ore processing.
– High-temperature and circular-saw cutting operations generate particles of less than one micrometer, sometimes with bimodal log-normal particle size distributions.

This publication concludes that in view of the wide range of AMAD values encountered in the literature, great attention should be paid to air sampling in order to characterize the particle size distribution for each professional activity, not least because the default AMAD value of 5 micrometers does not always maximize the calculated doses.

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<td>2/7*-2/13* – 60</td>
<td>2* 1</td>
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</table>

**R. 39 | Which default absorption type and particle size should be used? (GRADE A)**

**THE ABSORPTION TYPE** depends on the chemical form.

When the chemical form is known, use the values shown in tables 3.2 and 3.3 of the Appendix of the Decree dated 1/9/2003:
– pulmonary absorption type (F, M or S) in the case of inhalation,
– value of the gastrointestinal absorption factor \( f_1 \) (soon to be denominated \( f_A \)) in the case of ingestion.

These values influence the choice of the effective dose coefficient to use.

When the chemical form is unknown, use the values corresponding to “unspecified compound” in tables 3.2 and 3.3 of the Appendix of the Decree dated 1/9/2003.

**A DEFAULT PARTICLE SIZE** of 5 micrometers is used (ICRP) in the case of inhalation at a workplace.

**Q. C-1-5 | How should a mixture of radioisotopes and/or radionuclides be treated?**

**REGULATIONS**

No references

**INTERNATIONAL RECOMMENDATIONS AND STANDARDS**

**ISO 20553 [3-1; 2006]**

(§5) “In the case of mixtures where the radionuclide composition is well known, it is possible to use the measurement of a single radionuclide to infer the activities of the others. This approach is acceptable if the additional uncertainty (in terms of dose) arising from the incomplete knowledge of the radionuclide composition does not exceed 10 %.”

**ICRP 78 [2-13; 1998]**

(§115) “Workers may be exposed to mixtures of radionuclides and this must be taken into account in calculating pre-determined derived investigation levels. It will often be the case that only a few radioisotopes in the mixture make a significant contribution to the committed effective dose. In principle, the radiologically significant radionuclides should be identified and monitoring programmes should be designed to assess intake and committed effective dose for these radionuclides. However, there may be circumstances where it is easier to measure one of the other, less radiologically significant, radionuclides and to use this as a ‘tracer’ for the mixture. This is feasible when the composition of the mixture is well-known and constant. A common example is the use of americium-241 as a tracer for plutonium isotopes.”
ICRP 66 [2-7; 1994]
ICRP Publication 66 [2-7], presently applied, considers that:

($\S\ 272$) “Generally it would be expected that the rate at which the particle dissociates is determined by the particle matrix and that, therefore, this would be the same for the decay product as for the parent. Hence $sp$, $spt$ and $st$ are assumed to be the same. A notable exception, however, is when the decay product is a noble gas, such as radon, in which case it might be expected to diffuse from the particle. The behaviour of dissociated material would, however, be expected to depend on its elemental form; therefore, $fb$ and $sb$ for a decay product would not necessarily be expected to be the same as for the parent, although in the absence of information it might well have to be assumed that they are.”

LITERATURE REVIEW
ANALYSIS OF EXPERIMENTAL DATA
The article by AL. Serandour and al in 2008 [159 – Level of Evidence 4] concerns an experiment (year not stated) on 4 groups of 30 rats contaminated by inhaling PuO$_2$ aerosols (dating from 1987). The goal was to estimate the pulmonary retention of the actinides after dissolution of PuO$_2$ aerosols. During this experiment, an influence of the ageing of the powders was revealed for the PuO$_2$ which was 15 years old (americium ~50% of the total alpha activity), americium having a behaviour close to type M, whereas plutonium remained close to type S, despite the fact that a short time after the synthesis of MOX the behaviours of plutonium and americium are very similar.

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<th>Note</th>
<th>Literature references</th>
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<tr>
<td>4</td>
<td>3/1*-2/7*-2/13* – 159</td>
<td>3*</td>
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</tbody>
</table>

UNPUBLISHED FEEDBACK
Feedback on contaminations occurring at EDF decommissioning worksites [unpublished data] show that in the case of a plutonium/americium mixture, the mixture has an absorption type somewhere between the type S of plutonium and the type M of americium.

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.

In the case of a mixture of radioisotopes or radionuclides, the method to apply is the following:

1. The general rule is to treat each radioisotope separately.
2. In the two special cases of uranium and plutonium, the alpha-emitting isotopes can be treated globally.

It is therefore permitted in cases of a mixture of radioisotopes of a given element, or in presence of a daughter product of a radionuclide, to perform a dose assessment based on the sum of the measured activities in the excreta or in vivo.

3. If any radioisotopes of a mixture are not measured, remember to take them into account in the calculation of committed effective dose.

To do this, estimate the intake based on the isotopic composition of the mixture supplied by the radiation protection department.

If the percentage is expressed as a percentage of mass, this must be converted into a percentage of activity using the specific activity coefficient. The table below shows these coefficients for the main radioisotopes found in the form of a mixture and not always measured.
SPECIFIC ACTIVITY CALCULATION

Specific activity = \( \frac{N_A \times \ln(2)}{A \times T_{1/2}} \) [sec]

- \( N_A \) is the Avogadro constant = 6.022 E+23
- \( \ln(2) \) is Neperian logarithm of 2 = 0.693
- \( A \) is the radioisotope’s mass number
- \( T_{1/2} \) is the radioactive half-life expressed in seconds

<table>
<thead>
<tr>
<th>RADIOISOTOPE</th>
<th>SPECIFIC ACTIVITY (Bq/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-234</td>
<td>2.3 E+08</td>
</tr>
<tr>
<td>U-235</td>
<td>8.0 E+04</td>
</tr>
<tr>
<td>U-238</td>
<td>1.2 E+04</td>
</tr>
<tr>
<td>Pu-238</td>
<td>6.3 E+11</td>
</tr>
<tr>
<td>Pu-239</td>
<td>2.3 E+09</td>
</tr>
<tr>
<td>Pu-240</td>
<td>8.4 E+09</td>
</tr>
<tr>
<td>Pu-241</td>
<td>3.8 E+12</td>
</tr>
<tr>
<td>Am-241</td>
<td>1.3 E+11</td>
</tr>
</tbody>
</table>

The position adopted by ICRP Publication 66, which considers that when elements are mixed within the same matrix their dissolution kinetics are identical, proves debatable inasmuch that various experimental data borne out by unpublished human data demonstrate the contrary (this issue is discussed further Topic C-4-3).

In the case of a mixture of radionuclides, details of the mixture’s isotopic composition must be obtained from the operator. The isotopic composition, generally expressed in percentages of mass, must be transformed into percentages of activity. To do this, use the specific activity coefficients (in Bq/g).

In the case of presence of different radionuclides, each radionuclide must be monitored and the dose calculated using the specific model.

\[
\text{Dose} = \left( \frac{\text{Al}}{\text{RN measured}} \times \text{Dose coefficient}_{\text{RN measured}} \right) + \left[ \left( \frac{\% \text{ in A}}{\% \text{ in A}} \right) \times \frac{\text{Al}}{\text{RN measured}} \times \text{Dose coefficient}_{\text{RN not measured}} \right]
\]

- \( \text{Al} \) = intake (incorporated activity)
- \( A \) = activity
- \( \text{RN} \) = radionuclide

If one of the radionuclides in the mixture is not measured in the individual analyses, its contribution to the dose is taken into account on the basis of the isotopic composition.
In the special case of a mixture of isotopes (RI) of uranium or plutonium, whose radioactive half-lives are of the same order of magnitude and whose biokinetic behaviours are considered to be identical:
– the calculations can be done by taking into account the sum of the activities of each radionuclide's isotopes (RI 1 to n),

\[
\text{Mixture dose coeff.} = \left[ \text{Dose coeff. RI 1} \times \% \text{ activity RI 1} \right] + \left[ \text{Dose coeff. RI 2} \times \% \text{ activity RI 2} \right] + \ldots + \left[ \text{Dose coeff. RI n} \times \% \text{ activity RI n} \right]
\]

Pu-241, a beta emitter, decays to Am-241 with a relatively short half-life (14.4 years) and is in general not measured in “excreta”. Its contribution to the dose must therefore be estimated from indirect information on its activity in an incorporated mixture of plutonium isotopes. Moreover, the interpretation of any Am-241 measurements more than a few months after a contamination incident must take into account the contribution of the Pu-241 decay, which may require expert assistance.

In the case of a mixture of plutonium oxide and americium, the mixture displays kinetics intermediate between those of plutonium and americium. Special attention must be paid to events occurring during decommissioning operations, since the physicochemical characteristics of the mixtures (dissolution parameters) change with ageing. This special case requires expert assistance.

**Q. C-1-6 | Summary:** which default parameters values should be used?

**REGULATIONS**
No references

**INTERNATIONAL RECOMMENDATIONS**
ICRP 78 [2-13; 1998]

(§92) “… Use of a standard biokinetic model may lead to a certain error in interpretation, but use of a specific model is not justified for small intakes and doses. An individual-specific analysis based on the biokinetic parameter values for the individual can be justified for intakes giving doses approaching the annual dose limit. One situation where the standard models cannot be used is when therapeutic action has been taken to enhance elimination of the radionuclide from the body.”

**LITERATURE REVIEW**
The literature review concerns above all of the presentation of situations in which the utilization of the ICRP default model and parameters does not yield a reliable assessed dose, as revealed by inconsistencies. In these situations it is necessary to envisage adjusting the parameters after examining their respective influence on the dose assessment. This analysis is developed later in this topic.

**TO SUMMARIZE**
For a standard evaluation, ICRP Publication 78 [2-13] gives the bioassay functions with the parameter values of the default model. These recommendations were used in the IDEAS Guidelines [56].

In the rest of this document, the term “default model” will be understood to encompass the biokinetic reference models and the associated default parameters.

It is necessary, when the standard model is not chosen, to identify the important parameters and fix their possible variations, making sure to justify the proposed variations by credible physiological reasoning. Changing the standard parameters modifies not only the interpretation in terms of intake, but also the dose coefficients.
In the absence of all information, we use the ICRP models with the default parameter values:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value to Use in the Absence of Any Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake mode</td>
<td>Single intake by inhalation</td>
</tr>
<tr>
<td>Intake time</td>
<td>Middle of the monitoring interval</td>
</tr>
<tr>
<td>Absorption type or $f_1$</td>
<td>As per tables 3.2 and 3.3 of Appendix III of the Decree dated 01/09/03</td>
</tr>
<tr>
<td>Particle size (AMAD)</td>
<td>5 micrometers</td>
</tr>
<tr>
<td>(AMAD: Activity Median Aerodynamic Diameter)</td>
<td></td>
</tr>
<tr>
<td>Compound type</td>
<td>Unspecified, as per tables 3.2 and 3.3 of Appendix III of the Decree dated 01/09/03</td>
</tr>
<tr>
<td>Dose coefficient $h(g)$ (formerly DPUI or $e(50)$ for the ICRP)</td>
<td>$h(g) = \text{coefficient of committed effective dose per unit intake}$ As per Table 3.1 of Appendix III of the Decree of 01/09/03 according to the intake mode, absorption type/$f_1$ and particle size. See use in R 48</td>
</tr>
</tbody>
</table>

The hypotheses concerning the choice of values need to be confirmed by verifying the consistency of the assessments obtained from each measurement result.

If a characterization of the physicochemical parameters (particle size, density, dissolution, etc.) is available, a specific model is used, although this generally necessitates the use of calculation software. This approach must be validated by experts.

Appendix 4 of the case statement gives examples of assessments calculated from bioassay measurements for Co-60 and Pu-239.
As part of either routine monitoring or special monitoring, a rapid interpretation of the first measurement results is necessary in order to decide whether to pursue the measurements and to define possible therapies.

This section replies to the following questions:
- Why define and use derived recording levels (DRL)?
- Which DRL values should we choose?
- How do we interpret the measurement results rapidly using the DRLs?

Q. C-2-1 | Why define and use derived recording levels (DRL)?

INTERNATIONAL RECOMMENDATIONS
ICRP 54 [2-4; 1997]
(§ 21-22) “Derived Reference Levels […] it is convenient to compare the measurement results directly with derived reference levels […] These calculations form the main subject of this report […] for a number of radionuclides of importance in occupational exposure.”

ICRP 78 [2-13; 1998]
(§112) “In many situations of potential exposure to radionuclides, it is convenient to set investigation levels for the quantities that are measured in monitoring programmes, i.e. whole body content, organ content, daily urinary or faecal excretion, activity concentration in air. The chosen value for the investigation level may be directly related to dose or intake and the data given the Annex can be used to calculate the value of the measured quantity that corresponds to the chosen level of intake or dose for the appropriate monitoring programme.”

LITERATURE REVIEW

METHODICAL APPROACH
The article by A. Hodgson and al in 2007 [94 – Level of Evidence 4] describes a simple method to verify that the dose level is below action levels. The problem concerns the dispersion of radioactive aerosols in the public environment. A procedure is described for Cs-137 and a 1 mSv dose. It concerns the level of activity of the radionuclide in the body and the excreta as a function of the time, taking into account the probable variations in the size of the aerosols and differences in the biokinetic behaviour of chemical forms. The information is presented in the form of graphs. This approach is proposed to be able to make rapid decisions in order to reassure the public when the number of people involved is potentially high. It does not pretend to be a substitute for individual dose assessments.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2/4*-2/13* – 94</td>
<td>2* 1</td>
</tr>
</tbody>
</table>

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.

At an operational level, for daily practice needs the WG considers it necessary to use operational values derived from the RLs [ICRP Publications 54 and 78], called derived recording levels (DRL) relative to the pre-defined recording level (RL) equal to 1 mSv.

These values expressed in Bq:
- concern measurements performed on the whole body, organs or biological samples,
- can be defined as part of routine monitoring or special monitoring protocols to interpret results when “positive” results occur during routine monitoring (without any identified event) or following identified events.
Operational values derived from the RLs [ICRP Publications 54 and 78], called derived recording levels (DRL), enable rapid and direct interpretation (without calculation) of the first measurement results.

The DRLs correspond to the values of activity expressed, at a given time \( t \), in Bq for retention and in Bq/day for excretion, following the intake at time \( t_0 \) leading to a committed effective dose equal to:
- the value of the RL in the case of a single incident,
- the value of the RL divided by the number of monitoring intervals (or measurements) over 12 consecutive months for routine monitoring.

The results of the first measurements can be compared to the DRL values (R43-R44) for routine monitoring and special monitoring following intake by inhalation.

For routine monitoring (R43), the DRLs are calculated to verify that the RL fixed at 1 mSv is not exceeded over 12 consecutive months.
If every examination value is less than the DRL, we can then consider that the 1 mSv dose is not exceeded over 12 consecutive months.

**a/ For routine monitoring,** the DRL value is determined according to the monitoring interval of the measurement considered, making the assumption of an intake either on the day after the previous measurements or in the middle of the monitoring interval. In order to be sure of being able to detect all doses exceeding 1 mSv over 12 consecutive months, applying the principle established by the ICRP, the DRL is calculated relative to the value of the recording level that we then divided by the number of monitoring intervals (or measurements) over 12 consecutive months for routine monitoring. Example: for quarterly monitoring, the DRL corresponds to a measurement result, assuming intake on the day after the previous measurement, corresponding to a dose of 0.25 mSv (¼ x 1 mSv).

<table>
<thead>
<tr>
<th>Gamma emitters</th>
<th>Co-58 (S), Co-60 (S), Ag-110m (S), Cs-137 (F), I-131 (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta emitters</td>
<td>H-3, C-14, P-32, Sr-90, Ni-63</td>
</tr>
<tr>
<td>Alpha emitters</td>
<td>Natural uranium UF₆ (F), UO₂ (S), Pu-238-239-240 nitrate (M) and oxide (S) Am-241 (M), Th-232 (S)</td>
</tr>
</tbody>
</table>

The WG calculated the DRL values for the monitoring intervals used in routine monitoring (R 43).

**b/ For special monitoring,** the DRL values can be calculated for specific days after the intake time. The WG proposes to give the values in the form of tables with an average value for the first 3 days and the value at day 10 (R44).

### ROUTINE MONITORING

| DRL formula | \[
\begin{align*}
\text{DRL} &= \frac{1 \times 10^{-3} \text{ Sv} \times f(t)}{\text{e}^{50} \text{ Sv/Be}} \times n\text{ [intervals]}
\end{align*}
\] |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>f(t)</td>
<td>Value of the retention or excretion function at time t since the day after the previous analysis or the middle of the interval</td>
</tr>
</tbody>
</table>

**SPECIAL MONITORING**

| DRL formula | \[
\begin{align*}
\text{DRL} &= \frac{1 \times 10^{-3} \text{ Sv} \times f(t)}{\text{e}^{50} \text{ Sv/Be}}
\end{align*}
\] |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>f(t)</td>
<td>Value of the retention or excretion function at time t of the measurement (after the event)</td>
</tr>
</tbody>
</table>
TABLE N°4. ROUTINE MONITORING: WHAT ARE THE DRL VALUES FOLLOWING INHALATION?

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>RADIONUCLIDE</td>
<td>ABSORPTION TYPE</td>
<td>SUBSTRATE</td>
<td>DETECTION LIMIT</td>
<td>MONITORING INTERVAL (MI) IN DAYS</td>
<td>START OF MI</td>
</tr>
<tr>
<td>Beta emitters</td>
<td>DRL in Bq/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tritium</td>
<td>Tritiated water</td>
<td>Urine</td>
<td>50 Bq/L</td>
<td>30</td>
<td>1.5 E+04</td>
</tr>
<tr>
<td>P-32</td>
<td>F compound</td>
<td>Urine</td>
<td>~ 5 Bq/L</td>
<td>30</td>
<td>4.0 E+01</td>
</tr>
<tr>
<td>Ni-63</td>
<td>M compound</td>
<td>Urine</td>
<td>15</td>
<td>2.5 E+01</td>
<td></td>
</tr>
<tr>
<td>Sr-90</td>
<td>F compound</td>
<td>Urine</td>
<td>0.2 to 0.8 Bq/L</td>
<td>30</td>
<td>3.0 E+00</td>
</tr>
<tr>
<td>Gamma emitters</td>
<td>DRL in Bq/24h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co-58</td>
<td>S compound</td>
<td>Urine</td>
<td>0.2 to 2 Bq/L</td>
<td>90</td>
<td>1.0 E+00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faeces</td>
<td>1 Bq/sample</td>
<td>90</td>
<td>6.0 E+00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WBC</td>
<td>50 to 150 Bq</td>
<td>180</td>
<td>1.7 E+03</td>
</tr>
<tr>
<td>Co-60</td>
<td>S compound</td>
<td>Urine</td>
<td>0.2 to 2 Bq/L</td>
<td>180</td>
<td>2.0 E-01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faeces</td>
<td>1 Bq/sample</td>
<td>180</td>
<td>1.0 E+00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WBC</td>
<td>50 to 150 Bq</td>
<td>180</td>
<td>1.0 E+03</td>
</tr>
<tr>
<td>Ag-110m</td>
<td>S compound</td>
<td>Urine</td>
<td>0.2 to 2 Bq/L</td>
<td>180</td>
<td>1.0 E-01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faeces</td>
<td>1 Bq/sample</td>
<td>180</td>
<td>3.0 E+00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WBC</td>
<td>50 to 150 Bq</td>
<td>180</td>
<td>1.5 E+03</td>
</tr>
<tr>
<td>Cs-137</td>
<td>F compound</td>
<td>Urine</td>
<td>0.2 to 2 Bq/L</td>
<td>180</td>
<td>5.0 E+01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WBC</td>
<td>50 to 150 Bq</td>
<td>180</td>
<td>1.0 E+04</td>
</tr>
<tr>
<td>I-131</td>
<td>F compound</td>
<td>Urine</td>
<td>1 to 2 Bq/L</td>
<td>15</td>
<td>4.0 E-01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thyroid</td>
<td>3 to 10 Bq</td>
<td>15</td>
<td>1.0 E+02</td>
</tr>
</tbody>
</table>
For uranium, for urinary and faecal excretions, the DRL values in the table are expressed for a natural isotopic composition or slightly enriched less than 3% (sum of the three isotopes U-234, U-235 and U-238).

For pulmonary retention, the DRL value is expressed for U-235.

A: Radionuclides commonly encountered in NIs.
B: Priority given to the most disadvantageous hypotheses, in normal working situations.
C: Nature of the substrate (WBC: whole body counting).
D: Detection limit (DL) appearing in tables R33-34, to orient the choice of the most pertinent examination. A DL greater than the DRL does not enable us to be sure of detecting an intake resulting in an effective dose exceeding 1 mSv.
E: Monitoring interval (MI) in days to be respected in routine monitoring.
F: DRL calculation for an intake occurring on the first day of the monitoring interval.

<table>
<thead>
<tr>
<th>RADIONUCLIDE</th>
<th>ABSORPTION TYPE</th>
<th>SUBSTRATE</th>
<th>DETECTION LIMIT</th>
<th>MONITORING INTERVAL (MI) IN DAYS</th>
<th>START OF MI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Th-232</td>
<td>M compound</td>
<td>Faeces</td>
<td>1.0 E-03 Bq</td>
<td>180</td>
<td>3.0 E-04</td>
</tr>
<tr>
<td></td>
<td>S compound</td>
<td>Faeces</td>
<td>1.0 E-03 Bq</td>
<td>180</td>
<td>1.0 E-05</td>
</tr>
<tr>
<td>Natural uranium UF₆</td>
<td>F compound</td>
<td>Urine ^1</td>
<td>2.0 E-04 to 5.0 E-04 Bq</td>
<td>90</td>
<td>5.0 E-02</td>
</tr>
<tr>
<td>Natural uranium UO₂</td>
<td>S compound</td>
<td>Urine ^1</td>
<td>2.0 E-04 to 5.0 E-04 Bq</td>
<td>90</td>
<td>2.0 E-04</td>
</tr>
<tr>
<td></td>
<td>Faeces ^1</td>
<td>1.0 E-03 Bq</td>
<td>180</td>
<td>3.0 E-03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lung ^2</td>
<td>3 to 27 Bq</td>
<td>180</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Pu-238 Nitrate</td>
<td>M compound</td>
<td>Urine</td>
<td>2.0 E-04 to 5.0 E-04 Bq</td>
<td>180</td>
<td>1.0 E-04</td>
</tr>
<tr>
<td></td>
<td>Faeces</td>
<td>1.0 E-03 Bq</td>
<td>365</td>
<td>2.0 E-04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lung</td>
<td>&gt; 3 000 Bq</td>
<td>365</td>
<td>1.0 E-01</td>
<td></td>
</tr>
<tr>
<td>Pu-238 Oxide</td>
<td>S compound</td>
<td>Urine</td>
<td>2.0 E-04 to 5.0 E-04 Bq</td>
<td>180</td>
<td>1.0 E-05</td>
</tr>
<tr>
<td></td>
<td>Faeces</td>
<td>1.0 E-03 Bq</td>
<td>360</td>
<td>2.0 E-03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lung</td>
<td>&gt; 3 000 Bq</td>
<td>360</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Am-241</td>
<td>M compound</td>
<td>Urine</td>
<td>2.0 E-04 to 5.0 E-04 Bq</td>
<td>180</td>
<td>2.0 E-04</td>
</tr>
<tr>
<td></td>
<td>Faeces</td>
<td>1.0 E-03 Bq</td>
<td>360</td>
<td>2.0 E-04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lung</td>
<td>8 to 20 Bq</td>
<td>180</td>
<td>2.0 E-01</td>
<td></td>
</tr>
</tbody>
</table>

^1 For uranium, for urinary and faecal excretions, the DRL values in the table are expressed for a natural isotopic composition or slightly enriched less than 3% (sum of the three isotopes U-234, U-235 and U-238).
^2 For pulmonary retention, the DRL value is expressed for U-235.
**TABLE N°5. SPECIAL MONITORING: WHAT ARE THE DRL VALUES FOLLOWING INHALATION?**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RADIONUCLIDE</strong></td>
<td><strong>ABSORPTION TYPE</strong></td>
<td><strong>SUBSTRATE</strong></td>
<td><strong>DETECTION LIMIT</strong></td>
<td><strong>EARLY MEASUREMENT</strong></td>
<td><strong>MEASUREMENT AT DAY 10</strong></td>
</tr>
<tr>
<td><strong>Beta emitters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tritium</td>
<td>Tritiated water</td>
<td>Urine</td>
<td>50 Bq/L</td>
<td>1.0 E+06</td>
<td>7.0 E+05</td>
</tr>
<tr>
<td>P-32</td>
<td>F compound</td>
<td>Urine</td>
<td>~ 5 Bq/L</td>
<td>2.5 E+04</td>
<td>3.0 E+03</td>
</tr>
<tr>
<td>Sr-90</td>
<td>F compound</td>
<td>Urine</td>
<td>0.2 to 0.8 Bq/L</td>
<td>9.0 E+02</td>
<td>1.4 E+02</td>
</tr>
<tr>
<td><strong>Gamma emitters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Co-58</td>
<td>S compound</td>
<td>Urine</td>
<td>0.2 to 2 Bq/L</td>
<td>1.6 E+03</td>
<td>1.5 E+02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faeces</td>
<td>1 Bq/sample</td>
<td>6.4 E+04</td>
<td>3.6 E+02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WBC</td>
<td>50 to 150 Bq</td>
<td>1.5 E+05</td>
<td>3.5 E+04</td>
</tr>
<tr>
<td>Co-60</td>
<td>S compound</td>
<td>Urine</td>
<td>0.2 to 2 Bq/L</td>
<td>1.6 E+02</td>
<td>1.6 E+01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faeces</td>
<td>1 Bq/sample</td>
<td>6.5 E+03</td>
<td>4.0 E+01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WBC</td>
<td>50 to 150 Bq</td>
<td>1.5 E+04</td>
<td>3.8 E+03</td>
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<tr>
<td>Ag-110m</td>
<td>S compound</td>
<td>Urine</td>
<td>0.2 to 2 Bq/L</td>
<td>3</td>
<td>2</td>
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<tr>
<td></td>
<td></td>
<td>Faeces</td>
<td>1 Bq/sample</td>
<td>1.5 E+04</td>
<td>1.3 E+02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WBC</td>
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<td>1.0 E+04</td>
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<tr>
<td>Cs-137</td>
<td>F compound</td>
<td>Urine</td>
<td>0.2 to 2 Bq/L</td>
<td>1.5 E+03</td>
<td>4.0 E+02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WBC</td>
<td>50 to 150 Bq</td>
<td>8.0 E+04</td>
<td>6.3 E+04</td>
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<tr>
<td>I-131</td>
<td>F compound</td>
<td>Urine</td>
<td>1 to 2 Bq/L</td>
<td>9.0 E+03</td>
<td>1.0 E+01</td>
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<tr>
<td></td>
<td></td>
<td>Thyroid</td>
<td>3 to 10 Bq</td>
<td>1.1 E+04</td>
<td>5.0 E+03</td>
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<tr>
<td>RADIONUCLIDE</td>
<td>ABSORPTION TYPE</td>
<td>SUBSTRATE</td>
<td>DETECTION LIMIT</td>
<td>EARLY MEASUREMENT</td>
<td>MEASUREMENT AT DAY 10</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------</td>
<td>-------------</td>
<td>-----------------</td>
<td>------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Natural uranium UF₆</td>
<td>F compound</td>
<td>Urine ¹</td>
<td>2.0 E-04 to 5.0 E-04 Bq</td>
<td>1.0 E+02</td>
<td>4.0</td>
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<tr>
<td>Natural uranium UO₂</td>
<td>S compound</td>
<td>Urine ¹</td>
<td>2.0 E-04 to 5.0 E-04 Bq</td>
<td>4.0 E-02</td>
<td>5.0 E-03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faeces ¹</td>
<td>1.0 E-03 Bq</td>
<td>2.0 E+01</td>
<td>1.1 E-01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lung ²</td>
<td>3 to 27 Bq</td>
<td>2.0 E-01</td>
<td>2.0 E-01</td>
</tr>
<tr>
<td>Pu-238 Nitrate</td>
<td>M compound</td>
<td>Urine</td>
<td>2.0 E-04 to 5.0 E-04 Bq</td>
<td>5.0 E-03</td>
<td>5.0 E-04</td>
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<tr>
<td></td>
<td></td>
<td>Faeces</td>
<td>1.0 E-03 Bq</td>
<td>4</td>
<td>2.0 E-02</td>
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<tr>
<td></td>
<td></td>
<td>Lung</td>
<td>&gt; 3 000 Bq</td>
<td>2</td>
<td>1.7</td>
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<tr>
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<td>S compound</td>
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<td>2.0 E-04 to 5.0 E-04 Bq</td>
<td>1.0 E-04</td>
<td>2.0 E-05</td>
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<td>Faeces</td>
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<tr>
<td></td>
<td></td>
<td>Lung</td>
<td>&gt; 3 000 Bq</td>
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<td>5</td>
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<tr>
<td>Am-241</td>
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<td>Urine</td>
<td>2.0 E-04 to 5.0 E-04 Bq</td>
<td>3.0 E-02</td>
<td>2.0 E-03</td>
</tr>
</tbody>
</table>

¹ For uranium, for the urinary and faecal excretions, the DRL values in the table are expressed for a natural isotopic composition or slightly enriched less than 3% (sum of the three isotopes U-234, U-235 and U-238)  
² For pulmonary retention, the DRL values are expressed for U-235.

A: Radionuclides commonly encountered in NIs.  
B: Priority given to the most disadvantageous hypotheses, in normal working situations.  
C: Nature of the substrate (WBC: whole body counting)  
D: Detection limit DL appearing in tables R 33-34, to orient the choice of the most pertinent examination.  
E: DRL calculation for samples taken during the 3 first days.  
F: DRL calculation for samples taken on day 10.
Q. C-2-3 | How do we interpret the measurements results rapidly using the DRLs?

REGULATIONS
No references

INTERNATIONAL RECOMMENDATIONS
ICRP 54 [2-4; 1997]
(§ 21-22) “Derived Reference Levels
A measured value in excess of the derived recording level should be interpreted in terms of intake or committed dose equivalent and recorded in the formal dose record. A measured value below the derived recording level need not be interpreted in terms of committed dose equivalent or intake.”

ICRP 78 [2-13; 1998]
(§114) “If the investigation level is set at a level corresponding to a very low dose and intake, a measurement result less than the investigation level may require no action other than to record the fact that a measurement was made and the result was less than the investigation level. If, however, the investigation level corresponds to a significant fraction of the annual dose limit, measured values should be interpreted in terms of intake or dose.”

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
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</tr>
<tr>
<td></td>
<td>2*</td>
</tr>
</tbody>
</table>

DIAGRAM N°5. HOW CAN ROUTINE MONITORING RESULTS BE INTERPRETED QUICKLY.

R. 45 | How do we interpret routine monitoring results quickly? (GRADE A)

QUICK INITIAL ASSESSMENT

DRL table

Measurement result > DRL “start of interval” hypothesis

CONTROL MEASUREMENTS
GO ON TO SPECIAL MONITORING
Several types
Several measurements

Measurement results > DRL

ESTIMATE OF THE COMMITTED EFFECTIVE DOSE
See logical diagram C3

Ceasing of investigations

Level of evidence

<table>
<thead>
<tr>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>
R. 46 | How do we interpret special monitoring results quickly? (GRADE A)

DIAGRAM N°6. HOW CAN SPECIAL MONITORING RESULTS BE INTERPRETED QUICKLY.

QUICK INITIAL ASSESSMENT

- DRL table
- SPECIAL MONITORING MEASUREMENT
  MEASUREMENT RESULT > DETECTION LIMIT
  INITIAL GRADING OF THE EVENT
  - Negligible level < 0.1 mSv
  - Intermediate level 0.1 to 1 mSv
  - Significant level > 1 mSv

OTHER MEASUREMENTS

- For confirmation and validation
- 1 more “sensitive measurement”

- Other measurements
  - Several types
  - Several measurements

- Measurement results > DRL
- ESTIMATE OF THE COMMITTED EFFECTIVE DOSE
  See logical diagram C3

CEASING OF INVESTIGATIONS

DOSIMETRIC FOLLOW UP

129
C-3 | ASSESSMENT OF INTAKE AND COMMITTED EFFECTIVE DOSE

No specification is imposed in the regulations, excepting those in the Decree dated 01/09/03 [1-2] which applies the ICRP principles [2-13] as regards the calculation formulas.

The assessment of the committed effective dose over 50 years (E50) is based on an evaluation of the intake. The intake (Ai) is assessed based on measurements performed in vivo and/or on excreta.

This section replies to the following questions:
– How do we evaluate intake and committed effective dose?
– How do we exploit the measurement results?
– How do we handle the special case of a contaminated wound?

Q. C-3-1 | How do we evaluate intake and committed effective dose from the measurement results?

Q. C-3-1-1 | How do we evaluate the intake (formula)?

REGULATIONS
No specification is imposed in the regulations as regards the calculation formulas.

INTERNATIONAL RECOMMENDATIONS
ICRP 103 [2-17; 2007] (§139) “The system of dose assessment for intakes of radionuclides relies on the calculation of the intake of a radionuclide, which can be considered as an operational quantity for the dose assessment from internal exposure. The intake can be estimated either from direct measurements (e.g., external monitoring of the whole body or of specific organs and tissues) or indirect measurements (e.g., urine or faeces), or measurements on environmental samples, and the application of biokinetic models.”

LITERATURE REVIEW
The publications analysed use:
– either the principles approved by the ICRP,
– or an alternative method. This type of approach will be presented in Topic C-5 (alternative methods).

TO SUMMARIZE
The intake (Ai) is calculated based on measurements performed in vivo and/or on excreta.

In theory, for a given intake, the evaluations based on different measurement results should lead to the same value of intake. However, in practice we observe a dispersion of the results due to individual physiological variations and fluctuations relative to the models. This point is developed in Topic C-4.
### Literature references

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2/12*-2/13*-2/17*</td>
<td>3*</td>
</tr>
</tbody>
</table>

### Note

- \( m(t) \) is the value corresponding to the measurement result obtained by the laboratory from the whole body, organs or a biological sample. This value is used as-is, except in special cases (influence of a therapeutic treatment, for example) and/or in a case of inconsistencies in the different assessments.

- The calculated intake \([A_i]\) is then used to assess the dose.

\[
\text{Intake } A_i \text{ in Bq} = \frac{m(t)}{f(t)}
\]

\( f(t) \) is the value of the retention or excretion function corresponding to the quantity measured at time \( t \) following intake of 1 Bq at time \( t_0 \).

These values are published in the ICRP publications and IAEA reports (Safety Report 37).


### LITERATURE REVIEW

All of the publications adopt this formulation.

### INTERNATIONAL REGULATIONS AND RECOMMENDATIONS

A single specification exists and this concerns the calculation formula to apply: the Decree dated 01/09/03 [1-2] which reuses the recommendations made by the ICRP Publications.

ICRP 103 [2-17; 2007]

(§139) “The effective dose is then calculated from the intake using dose coefficients recommended by the Commission for a large number of radionuclides. Dose coefficients are given for members of the public of various ages and for adults who are occupationally exposed.”

### COMPLEMENTARY INFORMATION

The Working Group considers it necessary to provide elements of understanding on the ICRP’s recommended method.

The basic principle is the following. The internal dose is given by:

\[
\text{Dose} = \text{Number of Nuclear Transformations} \times \text{Dose per Disintegration}
\]

The number of nuclear transformations depends on the intake, its distribution in the body and the elimination kinetics.

The dose is said to be “committed” because it is received progressively after the intake throughout the period of presence of the radionuclide in the body.

---

**Q. C-3-1-2 | How do we assess the committed effective dose?**

R. 47 | How do we evaluate the intake from the measurement results? (GRADE A)
**How do we assess the committed effective dose?** (GRADE A)

The committed effective dose $E_{\text{internal}}$ ($E_{50}$), expressed in Sv, is given by the formula:

$$E_{\text{internal}} = \sum_j A_{\text{inh}}^j \times h(g)^{\text{inh}}_j + \sum_j A_{\text{ing}}^j \times h(g)^{\text{ing}}_j$$

where:

- $E_{\text{internal}}$: committed effective dose resulting from internal exposure (over 50 years $E_{50}$)
- $A_{\text{inh}}^j$ or $A_{\text{ing}}^j$: intake by inhalation or ingestion of the radionuclide $j$, expressed in Bq
- $h(g)^{\text{inh}}_j$ or $h(g)^{\text{ing}}_j$: committed effective dose per unit intake of the radionuclide $j$, expressed in Sv/Bq, inhaled or ingested by an individual in age group $g$ (called dose coefficient “e” – by the ICRP).

The $h(g)$ value to use is found in the appendices of the Decree dated 1 September 2003 [1-2]. This depends on the model chosen and the following parameters:

- isotope,
- intake route (inhalation, ingestion),
- absorption type (F, M, or S) according to the chemical form for inhalation,
- particle size (1 or 5 micrometers) for inhalation.

The dose coefficients for systemic absorption through healthy skin or a wound, are given in ICRP publications and NCRP and IAEA reports (see R 59).
even in this introductory chapter the necessity of having all dose assessments validated by a peer and obtaining expert help if one quarter of the regulatory limit is reached.

This value was chosen to be consistent with the regulations which require a declaration to the Nuclear Safety Authority (ASN) of any dose exceeding one quarter of a regulatory annual individual dose limit.

The method of validating the results and assessments as well as uncertainties, are developed in Topic C-4.

The WG introduces here an essential notion: the importance of the uncertainty levels associated with the assessment of effective dose following internal exposure. Nevertheless the WG underlines even in this introductory chapter the necessity of having all dose assessments validated by a peer and obtaining expert help if one quarter of the regulatory limit is reached.

This value was chosen to be consistent with the regulations which require a declaration to the Nuclear Safety Authority (ASN) of any dose exceeding one quarter of a regulatory annual individual dose limit.

The method of validating the results and assessments as well as uncertainties, are developed in Topic C-4.

The measurements must be pursued over time in order to improve the assessments of intake.

The assessment of intake and committed effective doses is complex. It is necessary to validate the results with a peer if the dose assessment is less than one quarter of the annual regulatory limit or with an expert if the assessment exceeds one quarter of the annual regulatory limit.

The validity of the calculation of the committed effective dose over 50 years resulting from internal exposure $E_{\text{internal}} (E_{\text{50}})$ is closely linked to the validity of the assessment of intake by inhalation.

The final value of the dose assessment can be validated when the control measurement results:
- have become less than the detection limit,
- are stable (plateau of the curve of the model or constant over three successive measurements)
- see R 61,
- and the intake evaluations based on each measurement result are consistent with each other (see R 61).

Occupational health practitioners are recommended to validate every assessment of committed effective dose with a peer or, when the estimated dose exceeds one quarter of the regulatory limit (5 mSv), with an expert.
**Exposure Circumstances**
- Radiation Protection
- Occupational Health Service

**Intake Time**

**Default Model and Parameter Values**
- In the absence of specific data

**ICRP**
- Retention and excretion fractions $f(t)$
- Dose coefficient $h(g)$
or $e_{50}$

**Use of the Measurement Results to Define $m(t)$**
- For each radioisotope in the mixture, even those not measured

**Assessment of the Intake**
- For each radioisotope in the mixture
  - $A_i = m(t) / f(t)$

**Estimate of the Committed Effective Dose**
- $E_{50} = A_i \times h(g)$

**Validation of the Estimates**
- Are there sufficient elements for the dose calculation?
- Consistency with the exposure data
- Consistency between the various estimations

**Prescription of New Measurements**
- Dose < 5 mSv
- Dose ≥ 5 mSv

Validation:
- With a peer
- With an expert

**Traceability Sheet**
- Expert report

**Test Results**
- Occupational Health Service Medical Biology Laboratory
- Sample validity
**DIAGRAM N°8. APPROACH TO ASSESS THE COMMITTED EFFECTIVE DOSE.**

(Left page).

The logical diagram below summarizes the steps of which some are developed under the following sub-topics. For understanding purposes, it is inserted at the beginning of this chapter.

---

**Q. C-3-2 | How do we exploit the measurement results?**

In some special cases, the measurement results are not directly exploitable for dose assessment.

This section replies to the following questions:
- What value should we attribute to results below the detection limit?
- In what conditions should we average the results of assessments from single measurement data?

**INTERNATIONAL RECOMMENDATIONS, REGULATIONS AND STANDARDS**

No references

**LITERATURE REVIEW**

**CASE STUDY ANALYSIS BASED UPON HUMAN DATA**

The article by JD. Boice and al in 2006 [26 – Level of Evidence 2] is an analysis of cases with human data in a context of a dose reconstitution a posteriori.

The study concerns a cohort of 5,801 workers subject to risks of external and internal exposure over the period from 1948 to 1999 in American nuclear installations.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Measurement Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>in the absence of suspicion of recent contamination</td>
<td>M = 0</td>
</tr>
<tr>
<td>if suspicion of contamination and/or a “recent” positive measurement</td>
<td>M = LD x 0.5</td>
</tr>
<tr>
<td>if suspicion of “recent” heavy contamination</td>
<td>M = LD</td>
</tr>
</tbody>
</table>

**METHODICAL APPROACH**

As complementary information, two articles [89-155] on the statistical analysis of data reveal the large bias generated by using different values for a variable equal to or less than the detection limit.

The article by D. Helsel in 1990 [89 - Level of Evidence 4] presents mathematical methods available for exploiting data below the detection limit for assessment purposes or to test hypotheses or regression: adjustment of a probability law (normal, log-normal, etc.) to the data to maximize its plausibility, parametric and non-parametric tests, robust linear Kendall correlation, Tobit regression, logistic regression.

The author judges that eliminating censored data or replacing them by fabricated values leads to undesirable and unnecessary errors.


The authors show that the sense and amplitude of the bias depends on the distribution of the exposure in the population, the recording threshold, the value allocated to results below the threshold and the measurement uncertainty.
TO SUMMARIZE

A measurement result reported as being less than the detection limit (DL) can correspond to any value of activity between 0 and DL. The context in which this measurement is performed orients the interpretation of such imprecise result.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
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</thead>
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<tr>
<td>3</td>
<td>26-89-155</td>
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</tr>
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</table>

R. 51 | **What value should we attribute to results below the detection limit?**  
**(GRADE B)**  

When a measurement result less than the detection limit (DL) is used for dose assessment:
– if this is an isolated measurement, it is recommended to use the DL value to estimate the maximum intake,
– if there are other “positive” results, it is recommended to use half the DL value to calculate the intake.

Q. C-3-2-2 | **In what conditions should we average the results of assessment from single measurement data?**

INTERNATIONAL RECOMMENDATIONS, REGULATIONS AND STANDARDS

No references

**US DEPARTMENT OF ENERGY STANDARD**

Already cited in C-1-3.
The US DOE standard of 1999 [2-35] suggests that the activity incorporated over a routine monitoring interval can be estimated from the arithmetic average of incorporated activity estimations, assuming intakes during each sub-interval of the monitoring period.

EUROPEAN WORKING GROUP REPORTS

**IDEAS GUIDELINES** [56; 2006] **LEVEL OF EVIDENCE 2**

These guidelines bear out the possibility of using the geometric mean. With a view to choosing the most plausible intake, the geometric mean of the assessments obtained independently from each measurement result is chosen. This approach enables extreme values to be weighted.

LITERATURE REVIEW

**CASE STUDY ANALYSIS BASED UPON HUMAN DATA**

The article by JW. Marsh and al in 2007 (130 – Level of Evidence 3) is an analysis of cases with human data.
The purpose of the study was to determine scattering factors (SF) for measurements as introduced by the IDEAS Guidelines by studying 51 cases of contamination published between 1960 and 2005. In these cases the dosimetric follow-up lasted several hundred to several thousand days and there was no decorporation treatment or measurements below the detection limit during the period studied.

The following method was applied:
1) Determine the trend curve of the measurements by adjusting a decreasing exponential function.
2) Calculate the standard deviation (scattering factor) of the values measured on this trend curve.
3) Use a chi-square test to verify that the scatter of the measured values corresponds to a log-normal distribution.
4) Combine the data taken from several cases of contamination with the same radionuclide, via the same intake route and for the same type of measurement.

The authors conclude:
– An interesting mathematical property when the measurement values display a log-normal distribution with the same scattering factor around the prediction of the biokinetic model is that the most plausible intake is the geometric mean of the estimations obtained from each measured value taken independently.
– When measurement values relating to the same intake have different scattering factors, these factors enable the measurement values to be weighted so as to evaluate the most plausible intake.
For a given event and for all of the associated results, the value of the intake is equal to the geometric mean of the intakes (A) estimated from each measurement result.

\[ \text{geometric mean} = \sqrt[n]{A_1 \times A_2 \times \ldots \times A_n} \]

Q. C-3-2-3 | How do we take into account the results of earlier events?

INTERNATIONAL RECOMMENDATIONS
ICRP 78 [2-13 ; 1998]
§107 “An intake in a preceding monitoring interval may influence the actual result obtained. If more than about 10% of the actual measured quantity may be attributed to intakes in previous intervals, for which intake and dose have already been assessed, a correction should be made. For a series of measurements in a routine monitoring programme, the following procedure may be observed:
(i) determine the magnitude of the intake in the first monitoring interval;
(ii) predict (from the graphs in the Annex or from Phipps and al., 1997) the contribution to subsequent measurement from this intake;
(iii) subtract this contribution from all subsequent data, and
(iv) repeat (i) to (iii) for the next monitoring interval.”

EUROPEAN WORKING GROUP REPORTS
IDEAS GUIDELINES [56 ; 2006] LEVEL OF EVIDENCE 2
The Guidelines state:
§6.3 “Calculation of the contributions P from previous intakes. The contributions (P) from all previous intakes of the radionuclide considered are calculated, taking into account all pathways of intake, and all intakes of mixtures where the radionuclide was involved. […] If a new intake is confirmed,] Calculate the net value (N = M – P) of the radionuclide by subtracting P from the measured value M.”

LITERATURE REVIEW
No references

TO SUMMARIZE
The residual values must be subtracted from the new results. For example:
- First contamination incident on 01/03 (with calculated intake A1)
- Second contamination incident on 01/06
- From the activity measured in urine on day 1 (rendered on 02/06) must be deducted the activity attributed to the first event, which is calculated using the formula:

\[ m(90) = A1 \times f(90) \]

where A1 = intake calculated following the incident on 01/03

Note | Literature references | Level of evidence
--- | --- | ---
3 | 2/35* – 6-130 | 1* 1 1

Note | Literature references | Level of evidence
--- | --- | ---
2 | 2/13* – 56 | 1* 1
For each new event, the activity retained or excreted from previous intakes (the residual) is deduced from the result of the last measurement. The opinion of experts may be necessary.

**CASE OF URANIUM**

**INTERNATIONAL RECOMMENDATIONS**

*ICRP 23 [2-1; 1975]*

(§ 3-0) For an unexposed population, the average daily intake of a natural uranium isotope compound is estimated at 1.9 microgram, [WG note, that is 47.5 mBq]. Thus, we have:
- an average urinary excretion of between 0.05 - 0.5 microgram /day, [WG note, that is 1.25 - 12.5 mBq/day]
- an average faecal excretion of between 1.4 – 1.8 microgram /day, [WG note, that is 35 – 45 mBq/day]

**UNSCEAR REPORT 2000 [2-34]**

The world average daily ingestion is estimated to be 16 mBq/day. The estimated average faecal excretion gives an alpha activity:
- for the sum of the three natural isotopes (U-238 + U-235 + U-234) of 15.6 mBq/day.
- for U-238 of 6.6 mBq/day [WG note : excretions estimated by calculation].

**NATIONAL REPORTS**

*INRS BIOTOX GUIDE [2007 - 14 LEVEL OF EVIDENCE 3]*

The guide chooses a value of 0.3 micrograms per litre of urine [WG note : 7.5 mBq/L] as the upper indicator value for the French unexposed population.

**LITERATURE REVIEW**

**CASE STUDY ANALYSIS BASED UPON HUMAN DATA**

The publications concern the excretion values of unexposed populations in different countries. The literature review reveals that natural urinary and faecal excretions vary between geographic regions.

The article by U. Oeh and al in 2007 [143- Level of Evidence 2] is an analysis of cases with human data. The authors analysed 60 urinary samples of people non occupationally exposed in six Jordanian towns in order to determine the natural uranium and thorium levels using ICP-MS. The excretions range from 0.2 to 42.5 mBq/day with an average of 3.95 mBq/day [WG note : 0.15 microgram/day].

The article by Al Jundi in 2004 and al [1 – Level of Evidence 2] is an analysis of cases with human data. The authors analysed 60 urinary samples of people non occupationally exposed in six Jordanian towns in order to determine the natural uranium and thorium levels using ICP-MS. The excretions range from 0.2 to 42.5 mBq/day with an average of 3.95 mBq/day [WG note : 0.15 microgram/day].

The article by C. Hurtgen in 2001 [95 – Level of Evidence 2] is an analysis of cases with human data. The authors synthesizes analyses carried out on urine and faecal samples. For 1,132 urine samples of workers potentially exposed to actinides, but not to uranium, the authors finds the interval 0.30 ± 0.34 mBq/day and an average U-234/U-238 ratio of 1.68 in urinary excretions.

For 39 faeces of workers potentially exposed to actinides, but not to uranium, the authors finds the interval 57 ± 68 mBq/day and an average U-234/U-238 ratio of 1.74 in faecal excretions.

The article by B.G. Ting and al in 1999 [167- Level of Evidence 2] is an analysis of cases with human data. The authors present the results of urinary bioassay measurements for uranium performed using ICP-MS.
between 1988 and 1994 on a population of 500 American residents. Half the unexposed people live in towns, half in rural zones. The ages ranged from 6 to 88 years. The average of the measured urinary excretions values is 11 nanogram/L and the value at the 95th percentile is 34.5 nanogram/L. [WG note: 0.86 mBq/L] The detection limit of the analytical technique is 1 nanogram/L. Values less than this detection limit were fixed at half this limit.

The article by M. Naumann and al in 1998 [141 – Level of Evidence 2] is an analysis of cases with human data. The authors present the data obtained from faeces of 10 unexposed inhabitants living near Berlin. The authors quantified the faecal excretion: – uranium:
  from 0.4 to 2.2 microgram/day (average 1.4 microgram/day)
  [WG note: 35 mBq/L]

UNPUBLISHED FEEDBACK
An unpublished study by a French laboratory completes these data. It concerns faecal bioassay measurements for uranium performed between October 2005 and December 2006 on 558 employees living near Paris and not exposed to uranium compounds. The average of the measured faecal excretion values (sum of the three natural isotopes U-238, U-235, U-234) is 48 mBq/day with an average U-234/U-238 ratio of 1.3.

TO SUMMARIZE
The literature review reveals that natural urinary and faecal excretion of uranium varies according to geographic regions.

SUMMARY TABLE N°6. NATURAL URINARY AND FEACAL URANIUM EXCRETION VALUES ACCORDING TO THE REGIONS.

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>YEAR</th>
<th>NUMBER OF PEOPLE STUDIED AND COUNTRIES</th>
<th>AVERAGE VALUE (mBq/day)</th>
<th>AVERAGE VALUE (nanogram/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRP 23</td>
<td>1975</td>
<td>Reference Man</td>
<td>12.5</td>
<td>500</td>
</tr>
<tr>
<td>BIOTOX</td>
<td>2007</td>
<td>French general population</td>
<td>7.5 mBq/L</td>
<td>300 nanogram/L</td>
</tr>
<tr>
<td>U. Oeh</td>
<td>2007</td>
<td>113 (Germany)</td>
<td>0.35</td>
<td>13.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,228 (Germany)</td>
<td>0.32</td>
<td>12.8</td>
</tr>
<tr>
<td>Al Jundi</td>
<td>2004</td>
<td>60 (Jordan)</td>
<td>3.95</td>
<td>150</td>
</tr>
<tr>
<td>C Hurtgen</td>
<td>2001</td>
<td>1 132 (Belgique)</td>
<td>0.2</td>
<td>10</td>
</tr>
</tbody>
</table>
**URINARY EXCRETION OF URANIUM (SUITE)**

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>YEAR</th>
<th>NUMBER OF PEOPLE STUDIED AND COUNTRIES</th>
<th>AVERAGE VALUE (mBq/day)</th>
<th>AVERAGE VALUE (nanogram/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.G. Ting</td>
<td>1999</td>
<td>500 (USA)</td>
<td>0.86 mBq/L</td>
<td>34.5 nanogram/L</td>
</tr>
<tr>
<td>MSE</td>
<td>1998</td>
<td></td>
<td>7 mBq/g of creatinine</td>
<td>300 nanogram/g of creatinine</td>
</tr>
</tbody>
</table>

**FAECAL EXCRETION OF URANIUM**

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>YEAR</th>
<th>NUMBER OF PEOPLE STUDIED AND COUNTRIES</th>
<th>AVERAGE VALUE (mBq/day)</th>
<th>U-234/U-238 RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRP 23</td>
<td>1975</td>
<td>Reference Man</td>
<td>45</td>
<td>1.5</td>
</tr>
<tr>
<td>UNSCEAR</td>
<td>2000</td>
<td></td>
<td>15.6</td>
<td>1.3</td>
</tr>
<tr>
<td>MSE</td>
<td>1998</td>
<td></td>
<td>70</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>C Hurtgen</td>
<td>2001</td>
<td>34 (Belgium)</td>
<td>57</td>
<td>1.74</td>
</tr>
<tr>
<td>Naumann</td>
<td>1998</td>
<td>10 (Germany)</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Unpublished study</td>
<td>2006</td>
<td>558</td>
<td>48</td>
<td>1.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>2/1*-2/33* – 1-14-95-116-141-143-167</td>
<td>2* 6 1</td>
</tr>
</tbody>
</table>

**CASE OF THORIUM**

**INTERNATIONAL RECOMMENDATIONS**

ICRP 23 [2-1; 1975]
The ICRP chose in its Publication 23 (1975), for natural isotopes and the unexposed population:
- world average daily ingestion of Th-232 of 3 microgram, or 12.3 mBq
- urinary excretion of 0.1 microgram/day. [WG note: 405 micro-Bq/day]
- faecal excretion of 2.9 microgram/day. [WG note: 11.8 mBq/day]

**UNSCEAR REPORT 2000 [2-34]**
The UNSCEAR chose, in this report, for natural isotopes and the unexposed population:
- world average daily ingestion of Th-232 of 2 microgram, or 8.2 mBq
- urinary excretion of 150 micro-Bq/day
- faecal excretion of 3.6 mBq/day [WG note: excretions estimated by calculation].
LITERATURE REVIEW

The publications concern the excretion values of unexposed people in different countries. The literature review reveals that natural urinary and faecal excretion varies between geographic regions.

CASE STUDY ANALYSIS BASED UPON HUMAN DATA

The article by G.S. Hewson in 1993 [92 – Level of Evidence 2] is an analysis of cases with human data. The author presents the results of analyses on 4 unexposed people in Australia. The urinary excretions are 5 nanogram/L, or 1.76 mBq/L. The serum activity was also measured for the same people, but no correlation is found between the two matrices.

The article by H.S. Dang and al in 1989 [45- Level of Evidence 3] presents a method including neutron activation followed by simple radiochemical separation that was developed and applied to determine thorium concentrations in blood serum and urine. The method is sufficiently sensitive to detect 0.025 mg of Th-232. The average thorium concentrations found in serum and urine of subjects in normal environments are respectively 7.9 and 2.7 nanogram/L.

The article by M. Naumann and al in 1998 [141 – Level of Evidence 2] is an analysis of cases with human data. The authors present the data obtained from faeces of 10 unexposed inhabitants living near Berlin. The authors quantified the faecal excretion:
- thorium:
  - Th-232 from 1.6 to 12 mBq/day (average 5.4 mBq/day)
  - Th-228 from 11 to 39 mBq/day (average 23 mBq/day)

The data in this article bears out the conclusions of the guide on uranium and thorium in the urine and faeces of non-exposed people.

The article by C. Hurtgen in 2001 [95 – Level of Evidence 2] mentioned previously synthesizes the analyses carried out on urine and faecal samples from 539 workers potentially exposed to actinides, but not to thorium. For thorium, the urinary excretion values are 230 ± 90 micro-Bq/day for Th-232. The Th-228 activities are always in excess relative to the father isotope Th-232. The ratio of Th228/Th232 activities is 2.6 for urinary excretions and 12.1 faecal excretions.

The data in this article bears out the conclusions of the guide on uranium and thorium in the urine and faeces of non-exposed people.

The article by Al. Jundi and al in 2004 [1 – Level of Evidence 2] mentioned previously shows that the Th-232 excretion range is from 1.4 to 640 micro-Bq/day with an average of 34.8 micro-Bq/day.

The article by C. Hurtgen in 2001 [95 – Level of Evidence 2] mentioned previously synthesizes the analyses carried out on urine and faecal samples from 539 workers potentially exposed to actinides, but not to thorium. For thorium, the urinary excretion values are 230 ± 90 micro-Bq/day for Th-232. The Th-228 activities are always in excess relative to the father isotope Th-232. The ratio of Th228/Th232 activities is 2.6 for urinary excretions and 12.1 faecal excretions.

The data in this article bears out the conclusions of the guide on uranium and thorium in the urine and faeces of non-exposed people.

TO SUMMARIZE

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>2/1*-2/33* – 1-45-92-95-119-156-167</td>
<td>2* 5 2</td>
</tr>
</tbody>
</table>
SUMMARY TABLE N°7. NATURAL URINARY AND FAECAL THORIUM EXCRETION VALUES ACCORDING TO THE REGIONS.

The literature review reveals that natural urinary and faecal excretion of thorium varies according to geographic regions.

**URINARY EXCRETION OF TH-232**

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>YEAR</th>
<th>NUMBER OF PEOPLE STUDIED AND COUNTRY</th>
<th>AVERAGE VALUE (micro-Bq/day)</th>
<th>AVERAGE VALUE (nanogram/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRP 23</td>
<td>1975</td>
<td>Reference Man</td>
<td>405</td>
<td>100</td>
</tr>
<tr>
<td>UNSCEAR</td>
<td>2000</td>
<td>World reference</td>
<td>150</td>
<td>37</td>
</tr>
<tr>
<td>MSE</td>
<td>2000</td>
<td></td>
<td>55</td>
<td>13</td>
</tr>
<tr>
<td>Al Jundi</td>
<td>2004</td>
<td>60 (Jordan)</td>
<td>35</td>
<td>9</td>
</tr>
<tr>
<td>C Hurtgen</td>
<td>2001</td>
<td>539 (Belgium)</td>
<td>230</td>
<td>57</td>
</tr>
<tr>
<td>B.G. Ting</td>
<td>1999</td>
<td>500 (USA)</td>
<td>13 micro-Bq/L</td>
<td>3.09 nanogram/L</td>
</tr>
<tr>
<td>P. Roth</td>
<td>1997</td>
<td>55</td>
<td>47</td>
<td>12</td>
</tr>
<tr>
<td>G.S. Hewson</td>
<td>1993</td>
<td>4 (Australia)</td>
<td>176</td>
<td>5</td>
</tr>
<tr>
<td>H.S. Dang</td>
<td>1989</td>
<td>11</td>
<td>16</td>
<td>3</td>
</tr>
</tbody>
</table>

**FAECAL EXCRETION OF TH-232**

<table>
<thead>
<tr>
<th>REFERENCE</th>
<th>YEAR</th>
<th>NUMBER OF PEOPLE STUDIED AND COUNTRY</th>
<th>AVERAGE VALUE (mBq/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRP 23</td>
<td>1975</td>
<td>Reference Man</td>
<td>11.8</td>
</tr>
<tr>
<td>UNSCEAR</td>
<td>2000</td>
<td>World reference</td>
<td>3.6</td>
</tr>
<tr>
<td>MSE</td>
<td>2000</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>C Hurtgen</td>
<td>2001</td>
<td>90 (Belgium)</td>
<td>3.4</td>
</tr>
<tr>
<td>Naumann</td>
<td>1998</td>
<td>10 (Germany)</td>
<td>28.4</td>
</tr>
</tbody>
</table>

**TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.**

Uranium and thorium are naturally present in the Earth's crust, but their concentrations vary between different regions. A daily intake of uranium and thorium via food of almost 1 microgram must be taken into account when interpreting measurement results.

Practically 100% of natural thorium is in the form of the isotope 232. Thorium is three to four times more abundant than uranium in the Earth’s crust.
Studies on non occupationally exposed populations have enabled estimates of average levels, from which reference values are defined. Nevertheless, high variability is observed, due to geographic and individual alimentary differences.

<table>
<thead>
<tr>
<th>RADIONUCLIDE</th>
<th>SUBSTRATE</th>
<th>CHOSEN REFERENCE</th>
<th>REFERENCE VALUE CHOSEN BY THE WG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium *</td>
<td>Urine</td>
<td>ICRP 23</td>
<td>0.5 microgram/L or 12.5 mBq/L (alpha activity) for natural isotopes *</td>
</tr>
<tr>
<td>Uranium *</td>
<td>Faeces</td>
<td>ICRP 23</td>
<td>45 mBq/day with U-234/U-238 ratio &lt; 2</td>
</tr>
<tr>
<td>Thorium 232</td>
<td>Urine</td>
<td>UNSCEAR</td>
<td>150 microBq/day for Th-232</td>
</tr>
<tr>
<td>Thorium 232</td>
<td>Faeces</td>
<td>ICRP 23</td>
<td>10 mBq/day for Th-232</td>
</tr>
</tbody>
</table>

*natural isotopic composition: U-234= 49%, U-238 = 49% and U-235 = 2% of total activity

To interpret analysis results concerning uranium and thorium, it is necessary to:
– verify the existence of occupational exposure,
– deduct the alimentary contribution.

To do this, the data supplied by the laboratory is:
– alpha activity of each natural isotope: U-238, U-235, U-234 and Th-230, Th-228, Th-232,
– sums (U-238 + U-235 + U-234) or (Th-230 + Th-228 + Th-232),
– the ratios U-234 /U-238 and Th-228/Th-232.

Knowledge of the isotopic compositions in urine and faeces enables a guide value to be subtracted for each isotope, or by mass.

In cases of occupational exposure to natural radioelements (uranium and thorium), the activity associated with the environmental contribution must be deducted from the measured activity. The environmental contribution of uranium and thorium can be estimated on the basis of individual data, or by using default average values.

If the laboratory has average values for the local unexposed population, or individual values measured prior to exposure, this data should be used in place of the default values.

In the absence of individual values, the following values should be subtracted for dose assessment purposes:
– Uranium in urine: 0.5 microgram/L, or 12.5 mBq/L (alpha activity) for a natural isotopic composition
– Uranium in faeces: 45 mBq/day for a natural isotopic composition and U-234/U-238 ratio < 2
– Thorium in urine: 150 micro-Bq/day for Th-232
– Thorium in faeces: 10 mBq/day for Th-232

When evaluating the intake, the administration of therapies must be taken into account:
– an evaluation of intake for a given time excludes any activity that has been excreted meanwhile,
– therefore this activity must be added to the evaluation to obtain the real initial intake.
**INTERNATIONAL RECOMMENDATIONS**

ICRP 78 [2-13; 1998]

(§88) “If medical intervention to prevent uptake or enhance excretion is considered, then it should be noted that any treatment will modify the biokinetic behaviour described by the models given in Section 3 and the data in the Annex cannot be used directly to assess committed effective doses when treatment has been administered. When therapy is used following an accidental intake, a programme of special monitoring should be undertaken to follow the distribution and retention of the particular contaminant in the person, and these data should be used to make a specific assessment of committed effective dose for that person.”

NCRP REPORT 161 [2-21; 2008]

NCRP report 161 (2008) “Management of People Contaminated with Radionuclides: Handbook” confirms the necessity of therapy following internal contamination by radionuclides. This report takes into account the data validated by international feedback.

**INTERNATIONAL RECOMMENDATIONS**

ICRP 75 [2-12; 1997]

(§266) “Intervention to reduce doses […] Examples are increased decorporation of actinides by chelating agents such as […] DTPA), forced diuresis after intakes of tritium, and prevention of radioactive iodine deposition in the thyroid by the administration of stable iodine.”

**NATIONAL REPORTS**

ASN GUIDE 2008 [5- LEVEL OF EVIDENCE 3]

The National Medical Intervention guide published by the ASN (2008 edition), for use in cases of nuclear or radiological events, proposes emergency therapies, in the current state of knowledge, based on medications that have a product marketing authorization (PMA).

<table>
<thead>
<tr>
<th>THERAPY</th>
<th>FDA 2009 INDICATION</th>
<th>COMPOSITION</th>
<th>PMA</th>
<th>PRESENTATION</th>
<th>COMMERCIAL DENOMINATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca-DTPA</td>
<td>plutonium, americium, curium</td>
<td>Ca-DTPA (iv formulation)</td>
<td>Yes</td>
<td>1 g</td>
<td>DTPA</td>
</tr>
<tr>
<td>Ca-DTPA</td>
<td>Ca-DTPA formulation (micronized powder)</td>
<td></td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IODINE</td>
<td>radioactive iodine</td>
<td>Potassium iodide (oral)</td>
<td>Yes</td>
<td>Tablets (65 mg potassium iodide)</td>
<td>Potassium iodide</td>
</tr>
<tr>
<td>PRUSSIAN BLUE</td>
<td>caesium radioactive</td>
<td>Insoluble ferric hexacyanoferrate</td>
<td>Yes</td>
<td></td>
<td>Radiogardase ®</td>
</tr>
</tbody>
</table>

**TABLE N°8. SPECIFIC THERAPIES LIMITED TO PROFESSIONAL EXPOSURES IN FRENCH NI(S).**

(taken from table 12.1 of NCRP report 161)

Q. | What is the impact of administering Ca-DTPA on the excretion and retention kinetics?

**INTERNATIONAL RECOMMENDATIONS**

ICRP 78 [2-13; 1998]

(Appendix A, §A.12 and §A.13) In cases of treatment by DTPA administration for contamination by plutonium or americium isotopes, “the excretion rate can be increased by as much as a factor of fifty […] Thus, the predicted values given [in annex A of ICRP publication 78] should be used with caution following administration of DTPA.”

NCRP REPORT 161 [2-21; 2008]

(§12.3.3) Following contamination by plutonium and americium isotopes, the dose reduction can be as much as 80% depending on the chemical form, the radionuclide intake route and the rapidity of injection.

(§21.4.8) The excretion can increase by a factor as high as 70.
Emergency DTPA treatment by injection or micronized solution.

LITERATURE REVIEW

CASE STUDY ANALYSIS BASED UPON HUMAN DATA


It reports observed results following 1,158 injections of Ca-DTPA used as a plutonium and americium sequestering agent, administered from 1970 to 2003 to 469 people involved in 548 events of internal contamination at CEA and AREVA centres in France.

This study underpinned the product marketing authorization (PMA) application of Ca-DTPA in injectable solution form [78].

The effectiveness on the day of injection is evaluated by the augmentation of urinary excretion, which ranges from 25 to 100 times. A nominal excretion factor of 50 is chosen.

The total effectiveness by injection includes the action of the Ca-DTPA during the following days. It takes into account the biological period of the Pu-DTPA complex which corresponds to the remanence of the Ca-DTPA action. This period is 1 to 5 days with a nominal (geometric mean) value of 2.25 days. On the basis of these parameters, the excretion factor for the total effectiveness by injection is estimated to be 150.

To observe a nominal pharmacological action of the Ca-DTPA thus defined, or a factor 150 per injection, there must be a minimum period of about 20 days between two injections. This delay reflects the remanence of sequestering agent’s action and the time necessary to refill, with circulating plutonium, the extra-cellular compartment accessible to the Ca-DTPA. In practice, more closely spaced injections are administered in severe cases, in order to maintain a high concentration of the sequestering agent in the blood and reduce the fraction fixing in the deposition organs.

The reference urinary curve for actinide excretion depends on the intake route and the physicochemical parameters of the radioelement. For assessment needs, the curves given in ICRP Publication 78 were used. The calculation was done for Pu-239 curves relating to wounds and inhalation of a type M (moderately soluble) compound and a type S (insoluble) compound. The monitoring duration is 1,000 days.

The dose-benefit represents the percentage of dose avoided thanks to the therapeutic action compared to the dose that would have been received without treatment. The observed levels of dose-benefit confirm the advantage of repeated injections at the start, whereas later treatments are significantly less beneficial.

The benefits of early treatment appear even more explicitly. We note the variability of the Ca-DTPA’s action according to the nature of the contamination, and also the confirmed validity of the current practice of prescribing intensive treatment in the weeks or months following the incident, then more widely spaced treatment and stoppage of the injections later.

The first Ca-DTPA injection made as soon as possible after the wound is intended to purge the body of circulating plutonium that is not yet fixed. This initial part of the kinetics does not appear explicitly on the urinary excretion curves and it involves a large fraction (about half) of the absorbed plutonium.

TO SUMMARIZE

To evaluate the effectiveness of Ca-DTPA, the individual urinary actinide excretion curve during Ca-DTPA treatment is compared with the excretion curve expected without treatment:

- the action factor is equal to the ratio U1/U0,
- the default action factor of Ca-DTPA is equal to 50,
- the true action factor of Ca-DTPA is evaluated at the end of a therapeutic window of at least 3 weeks by comparing urinary excretions over 24 hours before (U0) and after (U1) Ca-DTPA injection.

Note: the factor called “effectiveness factor” in the PMA corresponds rather to an action factor on urinary excretion. The effectiveness factor here is rather associated with the dose-benefit resulting from the treatment.
R. 55 | What is the impact of administering Ca-DTPA on the excretion and retention kinetics? (GRADE A)

Q. | What is the impact of stable iodine treatment on thyroid retention and urinary excretion?

INTERNATIONAL RECOMMENDATIONS

**NCRP REPORT 161 [2-21; 2008]**
Administering potassium iodide blocks or reduces the accumulation of radioactive iodine in the thyroid. The stable iodine must be administered as soon as possible, within 4 hours of the incident. In situations of continuous exposure, the effectiveness of taking iodine can be 50% even if taken 5 or 6 hours after contamination. All estimations of individual contamination or contamination levels suffer a degree of uncertainty. This uncertainty is smallest in estimations based on direct measurements on the thyroid.

NATIONAL REPORTS

**ASN GUIDE [5 – 2008 LEVEL OF EVIDENCE 3]**
Sheet 124: Iodine - Emergency treatment with potassium iodide

LITERATURE REVIEW

**METHODICAL APPROACH**
The article by PB. Zanzonico and al in 2000 [176 - Level of Evidence 4] is a mathematical (modelling) article. The authors calculated the protective effect of taking stable iodine as a function of the delay between the contamination and taking the tablets, and as a function of iodine intake in food. The administration of stable iodine up until 48 hours before exposure blocks almost totally the retention of radioactive iodine. When taken after contamination, the effect of the stable iodine is less and reduces faster in people whose iodine intake by food is insufficient. For example, the administration of potassium iodide 2 or 8 hours after contamination produces a respective protective effect of 80% or 40% in cases of sufficient intake by food, but only of 65% or 15% when the alimentary intake is deficient.

TO SUMMARIZE
The administration of stable iodine blocks the fixing of radioactive iodine in the thyroid, with some variability between individuals and the delay between this administration and the contamination. In view of this variability in the thyroid blocking provided by stable iodine and the fact that more than 99% of the effective dose in cases of iodine 131 contamination is due to its fixing in the thyroid, the dose assessment should be based on direct measurement of the activity effectively fixed in the thyroid.

Note | Literature references | Level of evidence
--- | --- | ---
6 | 2/13*-2/21* – 5-78-79-80 | 2* 3 1
R. 56 | What is the impact of stable iodine treatment on thyroid retention and urinary excretion? (GRADE A)

The administration of stable iodine reduces the fixing of radioactive iodine in the thyroid in proportions that depend on the delay between contamination and taking the iodine and on the regular alimentary intake of stable iodine. Consequently, the dose assessment must be based on direct measurement of the activity effectively fixed in the thyroid and not on urinary excretion measurements.

Q. | How do we take into account Prussian blue treatment after contamination by caesium isotopes?

INTERNATIONAL REPORTS

IAEA-TECDOC-1009 [1987; 2-31 - LEVEL OF EVIDENCE 2]

Administration of Prussian blue reduces the absorption of radioactive caesium in the gastrointestinal tract and thereby shortens its retention time in the body.

NATIONAL REPORTS

ASN GUIDE [5 – 2008 LEVEL OF EVIDENCE 3]

Sheet 113: Caesium - Emergency treatment with ferric ferrocyanide

R. 57 | How do we take into account Prussian blue treatment after contamination by caesium isotopes? (GRADE B)

When Prussian blue is administered after caesium contamination, the dose assessment must take into account the long-term biological retention period in the subject concerned, evaluated from whole body counting.

Q. C-3-3 | How do we handle the special case of a contaminated wound?

Operators manipulating radioactive sources are exposed to two distinct dermal risks:
- external contamination of healthy or injured skin (by wound, pin-prick, etc.),
- potentially associated with a systemic absorption if the skin is injured.

Two questions need to be addressed:
- How do we assess the local dose due to external contamination of healthy or injured skin?
- How do we estimate the systemic absorption and therefore the committed effective dose via a contaminated wound?
Q. How do we assess the local dose due to external contamination of healthy or injured skin?

**REGULATIONS**

**LABOR CODE IN FORCE ON 31/12/2010 [1-1]**

[R 4451-13] “For the skin, the exposure received over twelve consecutive months may not exceed 500 mSv. This limit applies to the average dose over any 1 cm² area, regardless of the surface exposed.”

**INTERNATIONAL RECOMMENDATIONS AND STANDARDS**

**ISO 15382 [3-3; 2002] STANDARD: PROCEDURE FOR RADIATION PROTECTION MONITORING IN NUCLEAR INSTALLATIONS FOR EXTERNAL EXPOSURE**

[§8.2.3]. “To assess the skin dose, determine the activity spread over the skin, the contaminated skin area, and the contamination duration, in addition to the composition of the radionuclides involved. Since the contamination is generally distributed non-uniformly over the skin, and the skin dose limits are defined taking into account the value the highest local skin dose, the activity, $A_n$, must be determined at the location of the maximum contamination.”

In the case of skin surface contamination, the skin dose, $H_{skin}$, is calculated using the formula:

$$H_{skin} = A_{f0} \cdot I \cdot \lambda^{-1} \cdot (1-e^{-\lambda t})$$

$$\lambda = \frac{\ln(2)}{T_{1/2}}$$

where $T_{1/2}$ is the half-life of the radionuclide.

The table below shows the equivalent dose rate factors for contamination of healthy skin:

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Equivalent dose rate factor (mSv/h/kBq/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>1.1</td>
</tr>
<tr>
<td>Pu-239</td>
<td>Not supplied</td>
</tr>
</tbody>
</table>

**TABLE N°9. EQUIVALENT DOSE RATE FACTORS FOR HEALTHY SKIN CONTAMINATION.**

(taken from Appendix C of ISO 15382 standard)

**ICRP 60 [2-6; 1990; §13] REUSED IN ICRP PUBLICATION 75 [2-12; 1997; §15]**

The 500 mSv limit for skin is derived from the recommended annual limit of 500 mSv at 70 micrometer depth for hand contamination, averaged over a 1 cm² area for workers.

**ICRP REPORT 156 [2-20; 2007]**

[§192]. The local dose assessment is based on the results of several measurements at variable geometries and times close to the contaminated wound. These results enable the contamination and its evolution to be characterized. The application of transport equations for photons, electrons and alpha particles in the biological tissue then provides an estimation of the average equivalent dose in a defined volume around the contamination.

The model enables the equivalent dose rate and the equivalent committed dose to cells to be determined, making assumptions as regards the minimum
contaminated area and the contamination type (superficial or at depth).

For example:

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Dose rate at the surface of healthy skin mSv/h/kBq/cm²</th>
<th>in a contaminated wound mSv/h/kBq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>0.78</td>
<td>0.15</td>
</tr>
<tr>
<td>Pu-239</td>
<td>Not supplied</td>
<td>0.011</td>
</tr>
</tbody>
</table>

**TABLE N°10. DOSE RATE AT THE SURFACE OF HEALTHY SKIN AND IN A CONTAMINATED WOUND.**
(taken from table 5.1 and 5.2 of NCRP Report, 2007)

**LITERATURE REVIEW**

In view of the recent data found in international reports, no bibliographic keyword search was performed.

The CEA report R-5441 [33 – 1988 - Level of Evidence 2] summarizes the problem of dermal contamination. It presents physiological data for the skin, detection and decontamination means, and above all it provides the equivalent dose coefficients for healthy skin for most radionuclides. These equivalent surface dose rate coefficients are used in NCRP Publication 156 [2-20] presented above. The authors apply and explain their calculations for concrete applications. For example:

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Radiation type</th>
<th>Equivalent dose rate for healthy skin mSv/h/kBq/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>Beta, electron</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>Gamma, X</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>0.78</td>
</tr>
<tr>
<td>Pu-239</td>
<td>Alpha</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Beta, electron</td>
<td>4.2 E-04</td>
</tr>
<tr>
<td></td>
<td>Gamma, X</td>
<td>1.0 E-03</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1.4 E-03</td>
</tr>
</tbody>
</table>

**TABLEAU N°11. EQUIVALENT DOSE RATE FOR HEALTHY SKIN.**
(taken from CEA report R-5441)

The CEA report R 5583 published in 1992 [34 – Level of Evidence 2] and examined in article [145] summarizes the problem of the local assessment associated with a contaminated wound. The authors clarify how to grade the initial event using a simple model. They chose, in first intention, a spherical source term of 0.5 cm radius introduced in a wound. They estimated the dose rate in a contaminated wound for common radionuclides. These rapid estimations enable a decision on surgical
intervention (e.g. excision).
This approach has been validated at international level.
For example:

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Dose rate in a contaminated wound mSv/h/kBq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>0.15</td>
</tr>
<tr>
<td>Pu-239</td>
<td>0.011</td>
</tr>
</tbody>
</table>

### TABLE N°12. LOCAL DOSE RATE IN A CONTAMINATED WOUND.
(taken from CEA report R 5583)

**CASE STUDY ANALYSIS BASED UPON HUMAN DATA**
The article by D. Broggio and al in 2009 [30 - Level of Evidence 3] is an analysis of cases with human data. Based on the study of a case involving a worker’s finger wound contaminated by Co-58 and Co-60, measurements and dose assessment were performed. The authors explain the use of nuclear magnetic resonance (MRI) type medical imaging of the patient and suitable software such as Œdipe (IRSN, France) which:
- improves the location and estimation of activity in the wound,
- compares the isodose curves with the local anatomy,
- determines the dose received by radiosensitive target cells.
However, one question that generally remains open from medical treatment and regulatory points of view is the optimal choice of the volume in which to calculate the equivalent committed dose.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Dose rate at the surface of healthy skin mSv/h/kBq/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>for uniform deposition for a 0.05 mL droplet</td>
</tr>
<tr>
<td>Co-60</td>
<td>0.78 0.22</td>
</tr>
<tr>
<td>Pu-239</td>
<td>1.6 E-03 8.5 E-04</td>
</tr>
</tbody>
</table>

### TABLE N°13. DOSE RATE AT THE SURFACE OF HEALTHY SKIN.
(taken from the Delacroix Practical Guide)

[WG note: experience of professional practices (unpublished) confirms the difficulties mentioned in this article.]

### REVIEW DOCUMENT
The Practical Guide written by D. Delacroix and al in 2006 [54 - Level of Evidence 4] summarizes, nuclide by nuclide, radiation protection data useful for radiation protection players. It gives for external contaminations of healthy skin, the equivalent dose rate coefficients for skin in two situations: first for a uniform deposition of 1 Bq/m² and, secondly, for a 0.05 mL droplet containing 1 Bq of the radionuclide. This guide is widely used in NIs.

For example:

TO SUMMARIZE
In cases of external contamination, the Occupational Health Service uses the standardized method detailed in NCRP Report 156. Based on the measurements repeated after each decontamination action in the medical block, measurements made using suitable probes help to:

1. Conduct the decontamination (start, end, etc.).
2. Determine its effectiveness.
3. Deduce the equivalent dose to the skin.
4. Monitor the detriment for the worker involved.
This method is applicable for assessing the local dose resulting from exposure of healthy or injured skin. The detriment depends on the dose absorbed in the basal layer of the epidermis.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>3/3-2/6-2/20 – 30-33-34-54-(145)</td>
<td>3* 2 1 1</td>
</tr>
</tbody>
</table>

R. 58 | How do we assess the local dose due to external contamination of healthy or injured skin? (GRADE A)

A dosimetric indication of local skin irradiation is given by the dose rate factors.
These are available in the international recommendations, standards and NCRP Report 156.

The dose delivered locally to healthy or injured skin must be validated with the assistance of experts, both as regards the measurements and the local dose assessments.

This provides useful indications for evaluating the health risk.

In the case of a wound, the local dose is not included in the calculation of committed effective dose in the absence of a tissular weighting factor \( w_T \) for the wound.

Q. | How do we estimate the systemic absorption and therefore the committed effective dose via a contaminated wound?

Following a skin lesion, a significant fraction of the intake generally passes into the blood immediately at the time of injury. Although a measurable retention remains in the wound for at least several days, it is necessary to model its kinetics to evaluate its contribution to the committed effective dose and, if need be, the local irradiation.

REGULATIONS

DEGREE DATED 1 SEPTEMBER 2003 [1-2]
[Article 1] “… The assessment of the effective dose takes into account, if need be, the committed dose following a wound that led to an internal contamination.”

INTERNATIONAL RECOMMENDATIONS

ICRP 78 [2-13; 1998]
(§22) “There is no general model of entry of radionuclides through the skin because of the large variability of situations which may occur.”
(§87) “When the skin is broken, punctured or abraded, radioactive material can penetrate to subcutaneous tissue and thence be taken up by body fluids. Depending upon the radionuclides and the amount of activity it may be necessary to undertake a medical investigation and a programme of special monitoring. In these circumstances, the amount of radioactive material at the site of the wound should be determined taking into account self-attenuation of the radiation in the foreign material and in tissue, as an aid to decision of excision. If an attempt is made to remove material from the wound, measurements should be made of the removed material and of any activity remaining at the wound site, so as to maintain an activity balance. Subsequently, a series of measurements should be made to determine uptake to body tissues. These measurements may consist of in vivo measurements, or urine or faecal excreta monitoring, as appropriate for the particular radionuclides. If whole-body measurements are made, it may be necessary to shield any activity remaining at the wound site. Uptake can be assessed from the data given in the Annex [functions for retention and excretion after injection]. In evaluating uptake, due account must taken of the effect of any treatment to enhance the removal of systemic activity.”

ICRP Publication 78 [2-13] provides excretion and retention functions following occasional injection of different radionuclides.
[WG note: Publication 78 does not give the coefficients of committed effective dose after injection.]

NCRP REPORT 156 [2-20; 2007]
Seven default categories for radionuclides retained in a wound – soluble with low, moderate, strong or avid retention, colloids, particles and fragments – are defined with corresponding exponential functions to model the retention kinetics in the wound (see table 5.11).
For example:

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Coefficients of committed effective dose per unit of systemic activity following injection (Sv/Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-60</td>
<td>1.95 E–08</td>
</tr>
<tr>
<td>Pu-239</td>
<td>4.93 E–04</td>
</tr>
</tbody>
</table>

**TABLE N°14. COEFFICIENTS OF COMMITTED EFFECTIVE DOSE PER UNIT OF SYSTEMIC ACTIVITY FOLLOWING INJECTION.**
(taken from table 5.3 of NCRP report 156, 2007)

From 2013, the ICRP plans to integrate the models from the NCRP report in its own recommendations and to provide the dose coefficients and corresponding retention/excretion functions.

**LITERATURE REVIEW**
This data being very recent, no publication was selected.

**TO SUMMARIZE**
Following an incident involving a contaminated wound, part of the activity is retained at the site of the wound while the rest is transferred to the regional lymph nodes and the blood.

1. The activity retained at the site of wound can be measured *in vivo* and be excised surgically. The residual activity may result in a large local dose.
2. The activity transferred to the lymph nodes irradiates them and slowly diffuses into the blood.
3. The activity transferred to the blood joins the systemic circulation, contributing to the committed effective dose. It is progressively excreted in the urine and faeces and can be measured by the usual analyses.

Unlike respiratory and digestive intake which correspond to physiological entry routes that can be modelled rather well in a generic manner, the wound is typically a pathologic situation whose modelling can provide only a very rough indication of what we might observe.

A significant fraction of the intake generally passes immediately into the blood at the time of injury, like an injection. If the retention at the site of the wound lasts at least several days, it is necessary to model its kinetics to evaluate the contribution to committed effective dose and, possibly, local irradiation. The chosen model can be validated by its consistency with the local and bioassay measurements.

**TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.**
Wounds must be treated on a case-by-case basis. The interpretation of the data necessitates various consistency comparisons between the available results and the calculated intake.

The classification of the compound in the definition of the category – soluble with low, moderate, strong or avid retention, colloids, particles and fragments – depends on the circumstances, for example:

– in a case of explosion, possibility of particles and fragments,

– in a case of a wound with projection of liquids, there will be soluble compounds whose retention depends on the chemical nature of the solution.

Similarly, surgical intervention to excise contaminated tissue perturbs the models established a priori, as does therapy using sequestering agents in the case of actinides.

For these reasons, expert assistance is necessary for dosimetric evaluation, or to confirm the one that may be performed.
How do we estimate the systemic absorption and therefore the committed effective dose via a contaminated wound? (Professional agreement)

In the case of a contaminated wound, an evaluation of the committed effective dose due to systemic absorption must be performed.

An indication of the dose is given by applying the ICRP injection model.

If the assessments of intake based on each measurement result are consistent, the chosen committed effective dose is equal to the intake multiplied by the dose coefficient from table 5.3 of NCRP Report 156.

If these assessments are inconsistent, other hypotheses on the category of the compound should be considered with expert assistance.

Long-term monitoring is often necessary to validate the hypotheses.

Practitioners are often concerned about the impact on dose assessment of uncertainties in the ICRP model parameters and in laboratory measurements. The questions they ask are:

- Why validate the dose assessment?
- How do we validate a dose assessment and the hypotheses used?

- Which parameters should be examined with priority when dose assessments are inconsistent?
- What can we say about the uncertainty in the dose assessment?
- What can we expect from dose assessment software?

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C-4 | How do we validate a dose assessment and what should we do when faced with inconsistencies?

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- What can we say about the uncertainty in the dose assessment?
- What can we expect from dose assessment software?
An analysis of these results shows that the latitude in the choice of the model and the necessity of making assumptions about certain exposure parameters, such as intake time, particle size and aerosol absorption type, when these are not known precisely, leads to high variability in the internal dose assessments done by different experts for the same cases.

**COMMITTEE EXAMINING RADIATION OF INTERNAL EMITTERS (CERRIE)**

This committee was established in 2001 by the UK government to “consider present risk models for radiation and health that apply to exposure to radiation from internal radionuclides in the light of recent studies and to identify any further research that may be needed.”

Composed of twelve members with different interests, including scientists associated with anti-nuclear groups, the nuclear industry and the National Radiological Protection Board (now the Health Protection Agency), it evaluated the available biological and epidemiological data on the effects of exposure to ionizing radiation and drew particular attention to the significant uncertainties in the dosimetric models and risk models.

The committee met 16 times from 2001 to 2004 and organized a workshop in 2003 to discuss its Preliminary Report. The final report [41], cited in ICRP Publication 103 [2-17], underlined that assessment of committed effective dose resulting from a contamination on the basis of bioassay measurement results is subject to uncertainty which can be as much as several orders of magnitude.

The results are shown in the table below:

<table>
<thead>
<tr>
<th>CASE 1</th>
<th>RANGE OF RESULTS</th>
<th>GEOMETRIC MEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26 micro-Sv to 64 mSv</td>
<td>25.8 mSv</td>
</tr>
<tr>
<td>CASE 2</td>
<td>0.47 to 0.82 mSv for Cs-137</td>
<td>0.66 mSv</td>
</tr>
<tr>
<td></td>
<td>1.74 to 37.2 mSv for Sr-90</td>
<td>7.22 mSv</td>
</tr>
<tr>
<td>CASE 3</td>
<td>2.73 to 9.45 mSv</td>
<td>5.0 mSv</td>
</tr>
<tr>
<td>CASE 4</td>
<td>2.2 to 3.0 mSv</td>
<td>2.57 mSv</td>
</tr>
<tr>
<td>CASE 5</td>
<td>8.2 to 118 mSv</td>
<td>27 mSv</td>
</tr>
<tr>
<td>CASE 6</td>
<td>8 to 331 mSv for Am-241</td>
<td>52.3 mSv</td>
</tr>
<tr>
<td></td>
<td>49 to 421 mSv for Pu-239</td>
<td>140 mSv</td>
</tr>
</tbody>
</table>

An analysis of these results shows that the latitude in the choice of the model and the necessity of making assumptions about certain exposure parameters, such as intake time, particle size and aerosol absorption type, when these are not known precisely, leads to high variability in the internal dose assessments done by different experts for the same cases.

It is necessary to validate all dose assessments due to the numerous factors of uncertainty:
- metrological uncertainty in the measurements,
- partial knowledge of the exposure conditions, even the time of exposure,
- variabilities between individuals,
- imperfect realism of the dosimetric models.
Static air samplers (SAS) are commonly used to monitor workplace conditions, but can underestimate concentrations in air in the breathing zone of a worker, typically by a factor of up to about 10.

Use of standard biokinetic model may lead to a certain error in interpretation, but use of a specific model is not justified for small intakes and doses. An individual-specific analysis based on the biokinetic parameter values for that individual can be justified for intakes giving doses approaching the annual dose limit.

exposure conditions:
– intake route: inhalation in both cases,
– chemical form: type S absorption for the first case, type M for the second,
– regardless of the particle size used.

Differences by a factor greater than 10 between the dose assessments obtained based on the different types of analysis call into question the default model and parameters used. These two situations were finally interpreted by taking specific parameters different from those of the ICRP model. This analysis was validated by experts.

According to the authors, these two cases illustrate the importance of respecting the following precautions during dose assessment:
– compare the assessment result with the initial conditions of the event;
– compare the different types of measurement results: urine, faeces, body;
– take into account the results of later measurement to check their consistency with the predictive values of the model;
– await the results of later measurement to evaluate the therapeutic effectiveness.

The article by N. Blanchin and al in 2008 [24 – Level of Evidence 3] presents an analysis of cases with human data concerning two contamination events involving plutonium inhalation. The analysis reveals discordant behaviour of the measurement results relative to the excretion functions of the ICRP models corresponding to the exposure conditions:
– intake route: inhalation in both cases,
– chemical form: type S absorption for the first case, type M for the second,
– regardless of the particle size used.

Differences by a factor greater than 10 between the dose assessments obtained based on the different types of analysis call into question the default model and parameters used. These two situations were finally interpreted by taking specific parameters different from those of the ICRP model. This analysis was validated by experts.

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– compare the assessment result with the initial conditions of the event;
– compare the different types of measurement results: urine, faeces, body;
– take into account the results of later measurement to check their consistency with the predictive values of the model;
– await the results of later measurement to evaluate the therapeutic effectiveness.

One unpublished result concerns the discovery of positive results at a zero point at the start of a worksite with alpha risks for a group of workers. Taking as a first approximation for each worker an intake time corresponding to their last intervention before the zero point, the estimated doses...
based on the results for a given worker, enables a contamination time to be targeted, identical for all of the workers. This date proved to be that of a cleaning intervention on the worksite where there was thought to be no contamination risk.

**TO SUMMARIZE**

Two publications and an unpublished observation of internal exposure events point to the necessity of validating the chosen dose assessment hypotheses by checking the consistency between the different data. The observed discrepancies relative to the default parameters used reflect the influence of a combination of physicochemical and physiological factors, although it is not possible to determine their respective weights.

The ICRP accepts:
- a difference factor of 3 in the assessments. This value is chosen for the variability associated with a given individual, therefore those associated with physiological variations or the use of the biokinetic models,
- a value of 10 for the variability of environmental parameters, relating to dispersion in the air.

**TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.**

The validation of the parameters used requires a verification of the consistency of the assessments based on different sets of data, rather than calculation of the uncertainties then definition of a target value.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2/13*-2/17* – 24-52</td>
<td>2* 1 1</td>
</tr>
</tbody>
</table>

The consistency of the estimations must be validated at three levels:

1. **Consistency of the assessments with the workplace exposure data**

   The chosen calculation model must be consistent with the initial data of the event, notably:
   - isotopes,
   - absorption type according to the chemical form,
   - particle size,
   - intake route.

   The intake time used must be validated with respect to the reality of the exposure periods.

   The estimated intake and the resulting committed effective dose must remain consistent with the estimated level based on the initial exposure data at the workplace, in particular:
   - the level of air contamination in the case of inhalation,
   - the result of the initial intake indicators.

   This consistency is considered to be acceptable if there is no more than a factor 10 between the levels of exposure and the real intake of the workers.

2. **Consistency of the intake calculated from each measurement result**

   The biokinetic and dosimetric model used is validated by checking the consistency of the intake assessments based on individual measurement results.

   This verification is done for all of the results of measurements of different types (in vivo, urine and faecal bioassay):
   - after their stabilization (plateau or less than the detection limit),
   - by comparing the measurement results of different types between each other and with the value predicted in the model.

   The hypotheses about intake conditions can be refined or validated by the consistency of the different
3. Consistency of estimations for workers exposed in the same conditions

When several workers are exposed to the same internal exposure event, it is preferable to prescribe the same measurements for all of these people:
- in order to validate the dose assessments,
- and for psychological and medico-legal reasons.

In the case of very different yet confirmed measurement results (differences greater than a factor of 10) between several workers exposed in the same conditions, this points to individual factors (physiological) and behavioural factors (absence of control, failure to wear individual protection equipment, etc.).

The consistency is considered to be acceptable if there is no more than a factor 3 between the estimations based on the different measurements.

intake estimations based on the results of several positive measurements.

The uncertainties are of two types:
- those relating to counting statistics (Poisson’s Law),
- those relating to metrology.

LITERATURE REVIEW

METHODICAL APPROACH

The article by G. Etherington and al in 2006 [62 – Level of Evidence 4] is a methodical approach that explains how the uncertainty in the exposure conditions can be represented by all of the possible hypotheses about intake time(s), absorption type, particle size and isotopic composition of the contaminant, if possible weighting them according to their plausibility.

As part of an expert assessment, more precise parameters such as the dissolution kinetics, the standard deviation of aerodynamic diameters and individual physiology can also be considered.

ISO 27048 [3-2; 2011]

§8.3.2 “If multiple measurements are made of the bioassay quantity, the uncertainty on assessed dose will be lower than that for a single measurement.”

The intra-individual variability of excretion generally displays a log-normal distribution characterized by its geometric standard deviation or scattering factor (SF).

REGULATIONS

No references

INTERNATIONAL RECOMMENDATIONS AND STANDARDS

ISO 27048 [3-2; 2011]

Table 6 presents sources of uncertainty in committed effective dose assessment to be considered according to the assessed dose:
- first, the intake time, particularly during routine monitoring,
- next, physiological and metrological uncertainties associated with measurement results in vivo and in vitro,
- finally, the variability in the characteristics of the compound involved (absorption type, particle size, mixture composition, gastrointestinal absorption factor) and the biokinetic data and dosimetric parameters.

ICRP PUBLICATIONS

All of the biokinetic and dosimetric models have been designed to represent a Reference Man whose anatomical and physiological characteristics correspond to average or median values of the adult population (ICRP Publications 23 and 89).

Q. C-4-3 | Which parameters should be examined with priority when dose assessments are inconsistent?
PARTICLE SIZE VARIABILITY

EXPERIMENTAL ANALYSIS

Two articles provide particle size measurement data performed in professional environments and complete the article of MD. Dorrian [60] cited in Subject C-1-4:

The study by P. Fritsch and al in 2007 [71 – Level of Evidence 4] concerns the size of aerosols present in the filters of air monitoring devices in workshops performing the MIMAS MOX fuel fabrication process. The analysis period is not stated. Measurements were performed using autoradiographic techniques. The AMAD measured on 23 filters is between 1.1 and 48 micrometers (median 8 micrometers), whereas the standard deviation (between 1.5 and 2.6 - median 2.1) is less than the proposed default value of about 2.5. These results show that the number of particles per Bq of aerosol of actinide oxides is generally much smaller than that calculated using the default parameters.

SPECIAL CASE OF MIXTURES

Reminder (see Topic C-1-5): the position adopted by ICRP Publication 66, which is to assume that for a mixture of elements within the same matrix their dissolution kinetics are identical, proves debatable inasmuch that various experimental data borne out by unpublished human data demonstrate the contrary.

CASE STUDY ANALYSIS BASED UPON HUMAN DATA

The article by N. Blanchin and al in 2008 already cited in C-4-2 [24 – Level of Evidence 3] concerns two very similar incidents of human exposure by inhalation of a mixture of actinides whose interpretation using the ICRP default model and parameters (Publication 78) does not yield a consistent dose assessment. The authors show that a hypothesis of specific physicochemical parameters yields a more consistent dose estimation. In particular, they make an assumption about a highly transferable (type F) form of plutonium and americium not described by the ICRP; this yields much better correlation between the examination results.

ANALYSIS OF EXPERIMENTAL DATA

The study by D. Boulaud and al in 2002 [28 – Level of Evidence 4] concerns data supplied by an impinger on a stream generator in dry phase during stoppage of the section 3 of the EDF nuclear power station at Cattenom in January 2001. The measurements concern 6 air samples in impingers in series on a manhole of the pressurizer in the dry and wet phases, at the bottom and on the edge of the pond, at the steam generator 4 in the dry and wet phases. A total of 29 isotopes were measured. The results reveal a particle size of the order of 1 micrometer, with standard deviations between 1.6 and 8.

The study by Al. Serandour and al in 2008 already cited in C-1-5 [159 – Level of Evidence 4] concerns an experiment on 4 groups of 30 rats contaminated by inhaling PuO$_2$ aerosols (dating from 1987). An influence due to the ageing of the powders was revealed for PuO$_2$, aged 15 years (americium ~50% of the total alpha activity), americium having a behaviour close to type M, whereas plutonium remained close to type S, despite the fact that a short time after the synthesis of MOX the behaviours of plutonium and americium are very similar.

The article by F. Paquet and al in 2003 [144 – Level of Evidence 4] concerns an experiment on 16 rats (duration of the study not stated) contaminated through a wound simulated by intramuscular injection of MOX powders (~25% Pu, synthesized 20 years earlier). Eight days after the contamination, the dissolution of the uranium (~65%) was 8 times higher than that of americium, and americium 5 times higher than that of plutonium.

The article by B. Ramounet and al in 2000 [153 – Level of Evidence 4] concerns an experiment on 3 groups of 30 rats (90 animals) with three types of industrial products (2 MOX, 1 PuO$_2$). The experiments lasted 7 days to 18 months according to the batches. The authors monitored the pulmonary clearance of these three compounds. They observed a difference between the dissolution kinetics of plutonium and americium (lower clearance for plutonium by a factor 2 or 3) and an effect of aging of the mixture for newly-synthesized industrial MOX compound.
UNPUBLISHED FEEDBACK

Feedback of contaminations that have occurred at EDF decommissioning worksites [unpublished data] shows that in the case of a plutonium/ americium mixture, the mixture displays an absorption type intermediate between the type S of plutonium and the type M of americium.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
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<td>10</td>
<td>3/2* – 24-28-56-62-71-144-153-159</td>
<td>1* 1 1 6</td>
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</table>

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.

The variability factors to be examined with priority are, in order of importance:

1. Concerning the reliability of the measurement result, in addition to the metrological uncertainty estimated by the laboratories, the variability factors to take into account are mainly those concerning the collection or sample quality (see subject B-4) and those concerning the influence of specific therapies (see Subject C-3-2-5).

2. The search for the time of the event should be taken into account:
   - prospectively to estimate the potential exposure at a workplace and the pertinence of the monitoring to be implemented,
   - in retrospect, when the measurement data is inconsistent with the model used, or when the committed effective dose may exceed the regulatory limit.

   If the intake time is unknown, the assessed effective dose is augmented or diminished by a factor 3 at most if the suitable monitoring interval is respected.

3. Concerning the characteristics of the contaminant mixture, the publications concerning human or experimental data reveal that:
   - Particle sizes can be highly variable in different occupational situations, which confirm the advantage of characterizing particle size distributions in specific occupational activities.
   - When the particle size is less than 5 micrometers, effective doses assessed using the default particle size 5 micrometers are likely to be diminished.
   - An increase of the dissolution associated with the ageing of the compounds appears linked to alpha irradiation. These results indicate that the dissolution parameters evolve over time.
   - This phenomenon must be taken into account, notably during decommissioning operations.

Specific absorption type can be assigned to a chemical compound using the methods described in the ICRP supporting guidance 3 [2002; 2-15].

4. In some rare cases of contamination with significant dose levels, the individual physiological variability, notably due to age, sex and health status, can be taken into account in the intake assessment when the available data makes this possible.

The variability factors to be examined with priority are, in order of importance:

- validity of each measurement result* (see the conformance criteria R28 to R32),
- influence of administered therapies (R55-56-57),
- intake time when this is not known (R38),
- particle size and the standard deviation of its distribution,
- absorption type.

* Note: any result, even if it does not meet the sampling or metrological conformance criteria, provides some information on the plausibility of the chosen hypotheses.

The opinion of experts may prove necessary. The practitioner and the expert will jointly choose new hypotheses.

R. 62 | Which parameters should we examine with priority when faced with inconsistent dose assessments? (Professional agreement)
the chi-square is given by:

$$\chi^2 = \sum \frac{\ln(M_i) - \ln[I \cdot m(t_i)]}{\ln(SF_i)}$$

The model is judged to be inconsistent with the measurements if the theoretical probability of finding a chi-square ($\chi^2$) value with (n-l-1) degrees of freedom greater than $\chi^2_0$ is less than 5%.

- The theoretical values of the chi-square distribution are given by statistical tables or software.
- It is also recommended not to use the model if the graphic trace of its prediction appears, according to an expert, to be inconsistent with the measurement values.

When the counting uncertainty is relatively low (<30%), the Guidelines suggest representing the total uncertainty on the measurement by a log-normal probability law with the following standard deviations (SF):

$$EUROPEAN WORKING GROUP REPORTS$$

$IDEAS GUIDELINES [56; 2006] LEVEL OF EVIDENCE 2$

By taking into account the uncertainties in the measurement and the exposure conditions, we can validate (or not) the consistency between the measurements and the chosen model, by means of a statistical test or expert judgment.

The Guidelines therefore propose a structured approach to adjust the model parameters to the measurements, according to the level of the estimated dose.

The consistency of the model’s predictions is evaluated as follows:

If we denote:

- $M_i$ (i = 1, ..., n), n measurement values observed at time $t_i$ after the intake I
- $m(t_i)$ predictions of the biokinetic model with l parameters, corresponding to an intake of 1 Bq
- SF, scattering factor associated with $M_i$

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When the counting uncertainty is relatively low (<30%), the Guidelines suggest representing the total uncertainty on the measurement by a log-normal probability law with the following standard deviations (SF):

$INTERNATIONAL RECOMMENDATIONS$

$ICRP 103 [2-17; 2007]$

($§165$) “The lack of certainty or precision in radiation dose models varies for the various parameters and the circumstances in defined situations. Therefore, it is not possible to give values for the uncertainties across the range of ICRP models, despite the fact that their assessment is an important part of model development. Uncertainties may need to be assessed however, for special cases, and approaches to their use have been described in a number of publications, … In general, it can be said that uncertainties for assessments of radiation doses from internal exposures, including the biokinetics of radionuclides, are larger than those from external exposures. The degree of uncertainty differs between various radionuclides.”

$ICRP 78 [2-13; 1998]$

($§92$) “The last factor to consider is the uncertainty on the assessment of dose from a given intake. Use of standard biokinetic model may lead to a certain error in interpretation, but use of a specific model is not justified for small intakes and doses. An individual-specific analysis based on the biokinetic parameter values for that individual can be justified for intakes giving doses approaching the annual dose limit.”

$REGULATIONS$

No references

$Q. C-4-4 | What can we say about the uncertainty in the dose assessment?
<table>
<thead>
<tr>
<th>MEASUREMENT TYPE</th>
<th>QUANTITY</th>
<th>SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiotoxicological analysis in vitro</td>
<td>True 24 h urine</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Simulated 24 h urine, creatinine normalised</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Urine (sample)</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>24 h faecal sample</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>72 h faecal sample</td>
<td>2</td>
</tr>
<tr>
<td>In vivo measurement</td>
<td>Energy &lt; 20 keV</td>
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</tr>
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<td></td>
<td>20 keV &lt; energy &lt; 100 keV</td>
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</tr>
<tr>
<td></td>
<td>Energy &gt; 100 keV</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Depending on the case, Marsh and al [130 – 2007 – following the IDEAS Guidelines- Level of Evidence 4] propose more precise values; or these can be introduced by an expert.

When the dose assessment is based on a single measurement, it can be useful to determine the confidence level of the measurement.

<table>
<thead>
<tr>
<th>2.5% confidence level</th>
<th>M / SF²</th>
</tr>
</thead>
<tbody>
<tr>
<td>97.5% confidence level</td>
<td>M x SF²</td>
</tr>
</tbody>
</table>

Source: ISO 27048 [3-2] standard

Note: assuming that the total uncertainty of the measurement respects a log-normal law with standard deviation SF, if we take as the 95% confidence interval two standard deviations on each side of the normal law, this is for the logarithm of the measurement: \[\ln(M) - 2 \ln(SF); \ln(M) + 2 \ln(SF)\].

Therefore, for the measurement this is the dose exponential: \[\frac{M}{SF²}; M \times SF²\].

LITERATURE REVIEW

METHODICAL APPROACH


The article by A. Birchall and al in 2010 [15 – Level of Evidence 4] is a methodical article. The authors show that knowledge of the uncertainty in the dose absorbed in the tissue where an effect occurs is important for the reliability of an epidemiological study or retrospective evaluations of individual health risk.

The article by J. Harrison and al in 2008 [84 – Level of Evidence 4] is a methodical article. The authors remind us that an evaluation of the uncertainties is not systematically necessary in a radiation protection approach. They underline that a realistic estimation of the uncertainty in the absorbed, equivalent or effective, is difficult and is itself subject to uncertainty depending on the quality and quantity of available information.

Estimations of the uncertainty are reported in several publications [4-47-48-62-71-77-129-134-138-148-149-174], but they belong to the field of expertise, and possibly research.

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
</table>
Knowledge of the uncertainty in the dose absorbed in the tissue where an effect occurs is important for the reliability of an epidemiological study and for retrospective evaluations of individual health risk. On the other hand, it is not systematically necessary in a radiation protection approach.

A realistic estimation of the uncertainty in the absorbed equivalent or effective dose, is difficult and is itself subject to uncertainty depending on the quality and quantity of available information. This requires expertise, and possibly research.

At a practical level, the Working Group selected the evaluation of uncertainties for dose values of about 100 mSv, in accordance with the position adopted in Topic D-1.

**TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.**

In the radiation protection context, the effective dose, which is compared to reference levels, constraints and dose limits, and used to optimize worker protection, is an indicator of the exposure of a reference individual represented by the biokinetic and dosimetric models. The ICRP [2-17] underlines that these models and the concomitant coefficients of committed effective dose are considered to be fixed, and free of associated uncertainty.

As part of an expert study, the uncertainty in the dose can be quantified based on that in the measurement and in the knowledge of the exposure conditions, in order to:
- estimate a health risk,
- guarantee a dose value with a required level of confidence,
- for prospective purposes, estimate the potential exposure at a workplace and suitability of the monitoring being conducted.

When a dose value may exceed 100 mSv, or when an evaluation of individual risk is necessary, any evaluation of the uncertainty in the dose assessment may be conducted with expert help.

**WHAT IS DOSE ASSESSMENT SOFTWARE?**

**LITERATURE REVIEW**

A literature review was conducted to constitute a list of existing software. All of the publications selected are articles describing the functionalities of the software, and in a few cases applications for which they have been used.

**AIDE (ACTIVITY AND INTERNAL DOSE ESTIMATES)**

L. Bertelli and al in 2008 [10 – Level of Evidence 4] describe the AIDE software used to calculate retained activities and committed doses following occupational exposure, and to estimate intakes and doses based on bioassay data, in accordance with the methods presented in ICRP Publication 78 [2-13], IAEA Safety Reports Series no.37 [2-30] and the IDEAS Guidelines [56].

It was used notably to assess doses after the Goiania accident (1987), as part of the ICRP quality assurance of dose coefficients calculation and for application of the contaminated wound model described in NCRP report 156 [2-20].

It allows parameter adjustments in the respiratory and systemic models.

**IDEA SYSTEM (INTERNAL EQUIVALENT DOSE ASSESSMENT SYSTEM)**

H. Doerfel in 2007 [58 – Level of Evidence 4] developed a programme called IDEA System designed to assist the implementation of monitoring and result interpretation in terms of committed effective dose and organ doses, inspired by the IDEAS Guidelines [56].

**IMBA (INTEGRATED MODULES FOR BIOASSAY ANALYSIS)**

dosimetric models to assess intake, organ doses and committed effective doses (by calendar year if need be).

The user can adjust the model’s parameters, search for the most plausible value of intake in the light of available measurements, using several exposure scenarios and in taking into account isotopic mixtures and measurements less than the detection limit.

IMBA is approved by the American Department of Energy (US-DOE) and other institutions, notably in United Kingdom.

**IMIE (INDIVIDUAL MONITORING FOR INTERNAL EXPOSURE)**

V. Berkovski in 2000 [7 – Level of Evidence 4] and V. Berkovski and al in 2007 [9 – Level of Evidence 4] describe the dose assessment software IMIE (RPI, Ukraine) and its application to one case of Co-60 inhalation and one case of Pu-239 inhalation, with determination of the most plausible absorption (with a mixture of types M and S) in view of the available measurement data, respectively lung and faeces.

**DOSAGE**

D. Nosske and al in 1998 [142 – Level of Evidence 4] have used the DOSAGE software to calculate doses resulting from cases of uranium and americium intake. It employs ICRP models with individually optimized parameters.

**LUDEP (LUNG DOSE EVALUATION PROGRAMME)**

N.S. Jarvis and al in 1994 [103 - Level of Evidence 4] describe the LUDEP software that employs the ICRP respiratory model to estimate the deposition and biokinetics of inhaled radionuclides and assess the corresponding doses.

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**REIDAC (RETSPECTIVE INTERNAL DOSE ASSESSMENT CODE)**


B.-W Chen and al in 2004 [38 – Level of Evidence 4] describe the INDO 2000 software used to assess intake and effective dose from measurement data following occupational exposure, employing the ICRP models and its recommendations and those of international reports [Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996)].

**MONDAL 2 (MONITORING TO DOSE CALCULATION VER. 2)**

N. Ishigure and al in 2004 [100 - Level of Evidence 4] describe the MONDAL 2 free software that employs the ICRP models to assess committed effective dose from bioassay measurements for workers and the public.

**INDOSE (INTERNAL DOSIMETRY)**

I. Silverman and al in 1999 [161 – Level of Evidence 4] describe the InDOse dose assessment software, including its application to assessment of intake and the corresponding dose in a case proposed during the third European dose assessment intercomparison exercise.

This programme employs the ICRP models and enables them to be modified.

**GENMOD (GENERAL MODEL)**

R.B. Richardson and al in 1998 [154 - Level of Evidence 4] describe the Genmod software that employs ICRP models to evaluate doses from measurement data. They also describe the dosimetric consequences of evolution of these models.

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WHAT CAN WE EXPECT FROM DOSE ASSESSMENT SOFTWARE?

LITERATURE REVIEW
The different publications describe the application of these programmes to dose assessment after internal exposure.

METHODICAL APPROACH
C. Hurtgen and al in 2007 [97-98 – Level of Evidence 4] describe the joint IDEAS/IAEA inter-comparison exercise conducted in 2005 on 6 cases of contaminations [57-97-98]. The following software was used:

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
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<tr>
<td>* each participating could use several software products</td>
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<tr>
<td>¹ IDEA-System, BKFIT, CINDY, INDO5, INDAC, INDO 2000, MMK-01, NIRS</td>
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</table>

REMINDER: RESULTS OF THE IDEAS/IAEA INTER-COMPARISON EXERCISE (ALREADY PRESENTED IN SUBJECT C-4-1)

<table>
<thead>
<tr>
<th></th>
<th>RANGE OF THE RESULTS</th>
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</thead>
<tbody>
<tr>
<td>Case 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case 2</td>
<td>0.47 to 0.82 mSv for Cs-137</td>
<td>0.66 mSv</td>
</tr>
<tr>
<td></td>
<td>1.74 to 37.2 mSv for Sr-90</td>
<td>7.22 mSv</td>
</tr>
<tr>
<td>Case 3</td>
<td>2.73 to 9.45 mSv</td>
<td>5.0 mSv</td>
</tr>
<tr>
<td>Case 4</td>
<td>2.2 to 3.0 mSv</td>
<td>2.57 mSv</td>
</tr>
<tr>
<td>Case 5</td>
<td>8.2 to 118 mSv</td>
<td>27 mSv</td>
</tr>
<tr>
<td>Case 6</td>
<td>8 to 331 mSv for Am-241</td>
<td>52.3 mSv</td>
</tr>
<tr>
<td></td>
<td>49 to 421 mSv for Pu-239</td>
<td>140 mSv</td>
</tr>
</tbody>
</table>

* each participating could use several software products
The dispersion of the results is not due to the performance of the dose assessment software, but to the hypotheses made.

E. Ansoborlo and al in 2003 [3 – Level of Evidence 4] tested six dose calculation programmes using the ICRP models to interpret bioassay data in two cases of contamination as part of a European intercomparison and according to several criteria. He obtained very homogeneous results.

The programmes used were MONDAL, IMBA, IMIE, BFS/ICRP 78 (BfS, Germany), developed for direct application of ICRP Publication 78 by a non-specialist user, plus UF and ID (LANL, USA) which calculate the posterior probability distributions of dosimetric variables of interest, and CALIN (AREVA-CEA, France) used for dose assessment by French occupational health practitioners.

Executing a reference calculation on an artificial sample, all of the programmes yield correct results in terms of intake and effective dose.

The authors conclude that two types of software can be used, depending on the level of expertise required:
- routine evaluation by a non-specialist user using default parameters and simple adjustment methods,
- “expert” programmes using specific parameters, data treatment and one or more methods of adjustment to judge the consistency of the estimations.

H. Doerfel and al in 2000 [57 – Level of Evidence 4] explain that during the 3rd European Intercomparison Exercise on Internal Dose Assessment, three families of software were used: commercial software such as GENMOD and CINDY based on the old ICRP models (in other words, ICRP Publications 30 and 54), commercial software such as LUDEP based on the most recent ICRP models (Publications 66, 67, 69), and several homemade programmes developed by users.

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.

Criteria (including the list in Appendix 7) to guide the choice of software can be defined.

The WG has not evaluated the software according to these criteria owing to the commercial nature of most of them. In addition, other criteria (price, frequency of use) specific to each user must also be taken into account.

These programmes are not indispensable, but they facilitate dose assessment by providing the dose coefficients and the excretion and retention functions corresponding to the standard models. They record the measurement data and perform the necessary calculations; they enable the predictions of the models, using different hypotheses, to be compared with measured results.

On the downside, the simplicity of testing different hypotheses about the physicochemical characteristics of the radionuclides or the biokinetic parameters can lead to large difference in calculated doses for a given event. This was revealed during the intercomparison exercises mentioned earlier.

The most-used software include:
- AIDE (Luiz Bertelli, USA, http:// aidesoftware.com/),
- CALIN (Atomic Energy and Alternative Energies Commission, France),
- IDEA (IDEA System, Germany, http://www.idea-system.com/),
- IMIE (Radiation Protection Institute, Ukraine, http://rpi.kiev.ua/products/IMIE/),

<table>
<thead>
<tr>
<th>Note</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
</table>
Dose assessment software products are available.

These use ICRP models to calculate retained and excreted activities, intake and committed effective dose from measurement results. They can also be used to validate the consistency of the results with the model and the chosen parameters, and to test other hypotheses if necessary.

On the other hand, these tools allow the model’s parameters to be freely adjusted to obtain the best consistency, which can lead to erroneous interpretations: mathematically consistent results may be obtained by making hypotheses that have no plausible justification. It is important that the hypotheses used remain consistent with the initial exposure conditions.

Optimal use of this type of tool requires some expertise, ideally in association with clinical practitioners and exploiting information as precise as possible about the exposure scenario.

Although experience shows that the default model is applicable in a large majority of situations, for a limited number of cases, as mentioned in the previous Subject C-4, the use of other dosimetric approaches proves necessary.

The default model is inapplicable in cases where:
- there is no inhalation, for example the case of a contaminated wound with systemic absorption,
- the different estimates are inconsistent with each other,
- the estimated dose is at a level that justifies additional estimations,
- there are no biokinetic data for the radionuclide concerned in the ICRP publications,
- it is necessary to assess the dose-benefit of a therapy.

Alternative approaches to the “default” model for evaluating committed effective dose are mentioned in ICRP publications.

A paper by Berkovski and al. (2003) indicated that an alternative approach may be more useful in some circumstances. There can be advantages in calculating the committed effective dose directly from the measurements using functions that relate them to the time of the intake. The measurements could be the whole body or organ content, urine or faecal sample, or even an environmental measurement. This approach would require that the Commission provides additional tables of ‘dose per unit content’ as a function of time after the intake for interpreting the measurement data, but this approach should facilitate the interpretation of monitoring data in many circumstances. It aids the analysis by ensuring that current models are used in the dose assessment and limits the opportunity to make errors by reading data from tables.”

“An individual-specific analysis based on the biokinetic parameter values for that individual can be justified for intakes giving doses approaching the annual dose limit.”

“... If realistic models are not available, it is appropriate to use models whose results are
LITERATURE REVIEW

METHODICAL APPROACH

The article by J. Piechowski and al in 1995 and 1996 [146 - 147 – Level of Evidence 4] cited in ICRP Publication 78 [2-13 §108] is an article explaining the so-called discrete deconvolution method. This is based on the fact that the measured activity retention or excretion is mathematically the convolution of the intake or activity absorption function over time with the retention or excretion function consecutive to intake or absorption of unit activity (1 Bq).

By considering the time day after day, discretely:

\[ m(t) = \sum_{\tau=0}^{t} A_i(\tau) \times f(t-\tau) \]

where:

- \( A_i(t) \) is the intake or absorbed activity (in Bq) on day \( t \)
- \( f(t) \) is the value of the retention or excretion function corresponding to the quantity measured \( t \) days after intake of 1 Bq
- \( m(t) \) corresponds to the value (in Bq) of the measurement result performed on the whole body, organs and/or biological samples by the laboratory on day \( t \)

The method consists in determining the value of the daily intake or absorbed activity from the entry routes into the blood, using the excretion or retention functions in an iterative loop (discrete deconvolution) to extract the values \( A(t) \) of the equation above.

As part of the IDEAS/IAEA intercomparison exercise on internal dose assessment, Hurtgen and al in 2007 [98 – Level of Evidence 2] describe a direct dose assessment method based on the use of specific effective energy values calculated by the ICRP [2-2] and apply it to intake of tritiated water. This was reused in the unpublished ICRP guide project on the interpretation of bioassay measurements [2-18].

The article by V. Berkovski and al in 2003 [8 – Level of Evidence 4] is a methodical approach. The authors propose to use the “dose per unit content” function as a robust and practical tool for interpreting bioassay data.

In addition to the direct deduction of the committed effective dose from the measured activity, without any evaluation of the intake, the dose per unit content functions prove relatively insensitive to the hypotheses about particle size and absorption type.

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS.

DISCRETE DECONVOLUTION METHOD

The application of this method to determine the activity absorbed in the blood during monitoring, using a urinary excretion or systemic retention
The ICRP “chronic intake” method is applied mainly when the analysis results are stable, reflecting a balance between daily intake and excretion. This situation may occur:

- either due to processes or work not performed in an enclosed space. Example: certain uranium chemistry operations performed in free air,
- or due to incomplete effectiveness of collective or individual protection. Example: exposure to tritium.

The Working Group recognizes the advantage of this method for retrospective assessments, for contaminated wounds and in cases of inconsistency between the monitoring results and the ICRP models. However, it recommends its use as an alternative method, since its application necessitates a computer tool.

**CHRONIC INTAKE METHOD**

Activity in (Bq)

Values of $u(t)$ or $r(t)$ according to the ICRP model, normalised by a 1 Bq.day$^{-1}$ intake

Values of $u_m(t)$ or $r_m(t)$ measured

**DIAGRAM N°9. CHRONIC INTAKE.**
In a situation of real chronic exposure, the ICRP provides the evolutions of activity in daily urine \( u(t) \) or retained \( r(t) \) in the body for a unit intake of 1 Bq/day.

Bioassay measurements are made as part of routine or special monitoring. They give the real kinetic evolution of the urinary excretion \( u_n(t) \) or the whole-body retention \( r_n(t) \).

The daily intake \( A_0 \) corresponds to the translocation of the theoretical curve to the experimental curve. At each measurement time \( t \), the daily intake \( A_0 \) is calculated, expressed as Bq/day, as follows:
- urine monitoring: \( A_0 = u_n(t) / u(t) \)
- body retention monitoring: \( A_0 = r_n(t) / r(t) \)

We obtain as many values of \( A_0 \) as there are measurements. These values are close only if the measured values are compatible with the model adopted by the ICRP. The intake \( A \) is then the geometric mean of the \( A_0 \) values obtained.

The coefficient of committed effective dose per unit intake \( h(g) \) expressed in Sv.Bq is supplied for an intake standardized at 1 Bq/day. If the intake is \( A \) and the number of days of exposure is \( n \), then the committed effective dose is:

\[
E_{50} = \frac{n \times A \times h(g)}{(Sv) \times (days) \times (Bq/day) \times (Sv.Bq)}
\]

**DIRECT DOSE ASSESSMENT METHOD**

A direct evaluation of the effective dose can be carried out independently of the intake route and biokinetic model in special cases where:
- the activity is distributed uniformly in the body, as for caesium, or can be measured in one organ that makes the principal contribution to the effective dose, as for iodine in the thyroid;
- the dosage contribution of radioactive daughters is negligible, or these are in equilibrium with the father nuclide, like Ba-137m and Cs-137.

**TO SUMMARIZE**

Alternative methods to the “default” model presented throughout this document can be useful when the default model does not enable a committed effective dose assessment of sufficient reliability.

These methods are beneficial when we grant more confidence to the analysis results than to the model:
- discrete deconvolution in cases of a contaminated wound,
- direct dose assessment when the individual physiology appears to differ from the biokinetic model.

For the time being, their application requires some expertise.

Additionally, the new international recommendations introduce a new way of interpreting measurement results by defining a dose coefficient directly relating to the measurement. This coefficient is
expressed in committed effective dose per measured unit of activity (DPUC) in a fixed matrix, in Sv per measured Bq.
This approach will circumvent the intake estimation and thereby simplify the committed effective dose assessment method.

However, it is too early to include this in the approach recommended by the Working Group.

When dose assessments appear inconsistent, other dosimetric approaches can be envisaged. The choice must be validated by experts.

**CHRONIC INTAKE METHOD**
The ICRP “chronic intake” method is applied mainly when the analysis results are stable, reflecting a balance between daily intakes and excretions. This situation may be observed:
– in cases of processes not performed in an enclosed space. Example: certain uranium chemistry operations performed in free air,
– in cases of ineffectiveness of collective or individual protection. Example: exposure to tritium.

**DIRECT DOSE ASSESSMENT METHOD**
Direct evaluation of the effective dose can be carried out independently of the intake route and a biokinetic model in special cases where:
– the activity is distributed uniformly in the body or can be measured in one organ that makes the principal contribution to the effective dose,
– the dosage contribution of radioactive progeny is negligible, or these are in equilibrium with their father nuclide,
– when there are strong inconsistencies in the intake estimates made using ICRP default models (inhalation and ingestion),
– to evaluate the equivalent committed dose in target organs other than the entry routes.

Application of this method necessitates a minimum number of measurements points of the same type: *in vivo* (whole body or thyroid) and *excreta* measurements.
The practical implementation of this method, which involves iterative calculations, requires a computer programme (CALIN, for example).

**DISCRETE DECONVOLUTION METHOD**
The “discrete deconvolution” method offers an alternative to the ICRP’s classic method of intake assessment (see R47). Its main advantage is that it avoids complex intake mechanisms, whose numerous physicochemical and physiological parameters are rarely known.
This is a good method to estimate systemic activity:
– in the case of a wound,
– when dose assessments appear inconsistent, other dosimetric approaches can be envisaged. The choice must be validated by experts.

**R. 65 | Are there alternatives to the use of the default model?**
(Professional agreement)
Topic D.
Health Risk and Its Management

By the Occupational Health Practitioner

D-1 | Health Risk Evaluation

This chapter on the evaluation of health risks aims to give practitioners information to help them respond to the anxiety of workers about their individual risk once a committed effective dose due to internal radioexposure has been assessed.

The recommendations made by the Working Group reply to two important questions:
- above which committed effective dose does the health risk need to be evaluated?
- how should it be evaluated?

Q. D-1-1 | Above which committed effective dose does the health risk need to be evaluated?

Regulations

Labor Code in Force on 31/12/2010 [1-1]
[R. 4451-86] “After any internal or external exposure occurring in the situations defined in Articles R. 4451-15 and R. 4451-77, the occupational health practitioner assesses the dose received due to this exposure and its effects on the exposed worker. If necessary, he can call on the IRSN (French Institute for Radiological Protection and Nuclear Safety).”

International Recommendations and Reports

ICRP 60 [2-6; 1990]
The ICRP defines protection variables (equivalent doses and effective doses) to determine dose limits for professional exposure and thereby ensure that the occurrence of stochastic health effects is maintained at an acceptable level and that tissular reactions are avoided.

(162) “[...] On the basis of the data presented above, the Commission has reached the judgement that its dose limit should be set in such a way and at such a level that the total effective dose received in a full working life would be prevented from exceeding about 1 Sv received moderately uniformly year by year and that the application of its system of radiological protection should be such that this figure would only rarely be approached. [...] The need to ensure that the limits provide protection against deterministic effects also has to be taken into account.”

ICRP 103 [2-17; 2007]
(156) “In retrospective assessments of doses to
specified individuals that may substantially exceed dose limits, effective dose can provide a first approximate measure of the overall detriment. […]"

(62) “In the case of cancer, epidemiological and experimental studies provide evidence of radiation risk albeit with uncertainties at doses about 100 mSv or less. […]"

LITERATURE REVIEW
“The carcinogenic risks of an exposure to ionizing radiation between 0.2 and 5 Sv have been estimated in numerous epidemiological studies. […]"

TO SUMMARIZE
Whatever the mode of exposure to ionizing radiation, by external irradiation or by internal contamination, the health effects depend on the dose received.

We must distinguish two types of effects, whose severity or incidence varies specifically with the radiation dose:
– “deterministic” effects, secondary to tissular reactions, characterized by a threshold dose above which lesions appear whose gravity increases with the dose (depletion of hematopoietic lineages, sterility, skin effects, etc.);
– “stochastic” or chance effects, in other words cancer and hereditary effects, for which the risk of occurrence increases with the dose, but whose severity is independent of the dose.

The ICRP has defined protection variables (equivalent doses and effective doses) to determine dose limits and thereby ensure that the risk of stochastic health effects is maintained at an acceptable level and that tissular reactions are avoided.

The available studies reveal no effect for doses less than 100 mSv, which means that either the effects are inexistent or that the statistical power of the investigations was insufficient to detect them. However, since some studies involved large numbers of subjects, this suggests that even if a risk exists, it must be very low.”

Regarding the stochastic effects, the literature review shows that for doses less than 100 mSv, allowing for the statistical uncertainties in the carcinogenic risk evaluations, these effects are not quantifiable by epidemiological studies.

When the dose assessment yields a committed effective dose lower than this value, the carcinogenic risk is low. Considering an excess of deaths by cancer of 5% per sievert (see topic D-1-2-1), the risk of mortal cancer after an exposure evaluated at less than 100 mSv, is less than 0.5 in 1000, a figure to compare with the natural risk of death from cancer, which is the primary cause of death (30% of deaths in France are due to cancer, BEH 2007).

Regarding deterministic effects, the ICRP says that restrictions of effective dose are sufficient to guarantee the absence of deterministic effects in most body tissue and organs, even when exposures are at dose limit level for relatively long periods.

TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS:

The Working Group considers it pertinent to evaluate carcinogenic risk and tissular effects when the assessed committed effective dose exceeds 100 mSv, following an internal exposure event. This value corresponds to the effective dose limit chosen by the ICRP averaged over 5 years.
Health risk evaluation concerns both deterministic and stochastic effects on exposed workers.

It is pertinent to evaluate the carcinogenic risk and tissular effects when the assessed committed effective dose exceeds 100 mSv, following internal radioexposure.

**INTERNATIONAL RECOMMENDATIONS AND REPORT**

**ICRP 103 [2-17; 2007]**

The ICRP has defined protection variables (equivalent doses and effective doses) to determine dose limits for professional exposure and thereby ensure that the risk of stochastic health effects is maintained at an acceptable level and that tissular reactions are avoided.

"In retrospective assessments of doses to specified individuals that may substantially exceed dose limits, effective dose can provide a first approximate measure of the overall detriment. If radiation dose and risk need to be assessed in a more accurate way, further specific estimates of organ or tissue doses are necessary, especially if organ-specific risks for the specified individuals are needed." [156]

"[…] For the assessment and judgement of individual cases absorbed doses to organs or tissues should be used together with the most appropriate biokinetic parameters, data on biological effectiveness of the ionising radiation and risk coefficients. In these cases uncertainties should be taken into consideration."

The ICRP publication 60 estimates the risk of death by cancer following irradiation at low-dose (<0.2 Sv) and low dose rate (<0.1 Sv/h) to be 4% per Sv for workers.

This evaluation of cancer risk was reviewed in ICRP Publication 103, resulting in a lowering of the nominal risk. This nominal risk (case for 10,000 people per Sv) of fatal cancer for the entire population was 5% in publication 60, then was re-evaluated to 4% (Table n°15). However, in publication 103, the ICRP no longer gives the global probability of mortal cancer for workers, but only a detriment estimated to be 4.1% per Sv. This figure takes into account not only the whole-life risk of radiation-induced cancer and the mortality fraction, but also the morbidity, suffering and reduced life expectancy associated with non-mortal cancers.

### TABLE N°15. DETRIMENT - ADJUSTED NOMINAL RISK COEFFICIENTS FOR STOCHASTIC EFFECTS AFTER EXPOSURE TO RADIATION AT LOW DOSE RATE (% / Sv).

(taken from ICRP Publication 103, table 1.)

<table>
<thead>
<tr>
<th>Exposed population</th>
<th>Cancers % / Sv</th>
<th>Heritable effects % / Sv</th>
<th>Total % / Sv</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CIPR 60</td>
<td>CIPR 103</td>
<td>CIPR 60</td>
</tr>
<tr>
<td>Whole</td>
<td>6.0</td>
<td>5.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Adult</td>
<td>4.8</td>
<td>4.1</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**BEIR VII PHASE II [2-34; 2006] - HEALTH RISKS FROM EXPOSURE TO LOW LEVELS OF IONIZING RADIATION**

The BEIR VII report, published by the National Research Council, presents risk evaluations for the incidence and mortality of cancer after low dose and low LET radioexposure. Based on the available epidemiological studies, it establishes models for specific sites of solid cancers and for leukaemia. These models can be used to calculate the excess relative risk (ERR) and excess absolute risk (EAR) as a function of the dose, the age at the time of exposure and the actual age. Using these models, the BEIR VII report calculates whole-life risks, in particular the number of cancers and the number of deaths by cancer due to exposure to a 0.1 Gy dose expected in a group of 100,000 persons (Table n°16) whose age distribution is similar to that of the population.
for chronic exposures in view of the dose-response models used to evaluate these risks.

IARC [2-36 ; 2001] MONOGRAPH ON THE EVALUATION OF CARCINOGENIC RISKS TO HUMANS, VOL. 78, IONIZING RADIATION, PART 2: SOME INTERNALLY DEPOSITED RADIONUCLIDES.

This report from the International Agency for Research on Cancer evaluates the carcinogenic nature of radioelements after internal contamination. It reviews the data on the exposure conditions (medical, environmental, animal experiments, etc.) and on the health effects revealed in the studies available at the time of writing.

The report concludes that the following radionuclides are carcinogenic (group 1): radium 224, radium 226, radium 228, thorium 232, plutonium 239, phosphorus 32, radioiodines, and incorporated alpha-emitting or beta-emitting radionuclides.

The BEIR VII report also provides attributable whole-life risks for the incidence and mortality of solid cancers and leukemia as a function of the age at the time of exposure (Tables 12-D-1 and 12-D-2).

The authors of this report published in 2006 consider that the available scientific data is compatible with a linear, no-threshold dose-effect relationship between radioexposure and cancer development in man.

UNSCEAR [2-32 ; 2006] “EFFECTS OF IONIZING RADIATION”. REPORT TO THE GENERAL ASSEMBLY WITH APPENDICES.

In a population including all age classes exposed to an acute dose of 1 Sv, the risk of death by solid cancer is estimated to be 4.3-7.2% and by leukemia to be 0.6-1%. These values also apply for chronic exposures in view of the dose-response models used to evaluate these risks.

IARC [2-36 ; 2001] MONOGRAPH ON THE EVALUATION OF CARCINOGENIC RISKS TO HUMANS, VOL. 78, IONIZING RADIATION, PART 2: SOME INTERNALLY DEPOSITED RADIONUCLIDES.

This report from the International Agency for Research on Cancer evaluates the carcinogenic nature of radioelements after internal contamination. It reviews the data on the exposure conditions (medical, environmental, animal experiments, etc.) and on the health effects revealed in the studies available at the time of writing.

The report concludes that the following radionuclides are carcinogenic (group 1): radium 224, radium 226, radium 228, thorium 232, plutonium 239, phosphorus 32, radioiodines, and incorporated alpha-emitting or beta-emitting radionuclides.

TABLE N°16. LIFE-TIME ATTRIBUTABLE RISK OF INCIDENCE AND MORTALITY FOR ALL SOLID CANCERS AND LEUKAEMIA PER 100,000 PERSONS EXPOSED TO 0.1 GY.
(taken from table 12-13 of the BEIR VII report phase II)

<table>
<thead>
<tr>
<th>All solid cancers</th>
<th>Leukemia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
</tr>
<tr>
<td>Excess cases (including non-fatal) from exposure to 0.1 Gy</td>
<td>800 (400 - 1,600)</td>
</tr>
<tr>
<td>Number of cancers in the absence of exposure</td>
<td>45,500</td>
</tr>
<tr>
<td>Excess deaths from exposure to 0.1 Gy</td>
<td>410 (200 - 830)</td>
</tr>
<tr>
<td>Number of deaths in the absence of exposure</td>
<td>22,100</td>
</tr>
</tbody>
</table>

LITERATURE REVIEW

AUTHOR’S OPINION

The article by J.D. Harrison and al in 2007 [85 – Level of Evidence 4] is an author’s opinion. The authors remind us that equivalent doses and effective doses cannot be exploited to evaluate doses and risks precisely for a given individual in cases of accidental contamination in which the doses can exceed the limits. In such cases, the doses absorbed in organs and tissue should be used and estimated specifically for the person concerned by adapting the biokinetic and dosimetric hypotheses. The risk coefficients applied must, if possible, be adapted to the gender and age of the individual. In this type of evaluation, it may be useful to take uncertainties into consideration.

TO SUMMARIZE

The estimation of the carcinogenic risk in a given individual is based on the use of risk coefficients (estimations of risk per dose unit).

These risk coefficients are derived from epidemiological studies or publications of various institutions, notably the United Nations Scientific Committee
of the Effects of Atomic Radiation (UNSCEAR), the Committee on the Biological Effects of Ionizing Radiation (BEIR) at the National Academy of Sciences, and the International Commission on Radiological Protection (ICRP), which have made estimations of the cancer risk associated with radiation exposure.

The estimations made by these bodies are mainly derived from studies on the survivors of the nuclear bombadments of Hiroshima and Nagasaki, and on groups of people who have received irradiation doses for therapeutic or diagnostic purposes, or who were exposed in their work (uranium miners, clock face painters using radium).

The data on tumorigenesis base mechanisms, the so-called “microscopic approach”, also enables dose-effect relationships to be extrapolated to doses less than those for which quantitative information from epidemiological studies is available.

The risk coefficients derived from epidemiological studies, which consider an exposure mode and an effect, are generally expressed relative to the absorbed dose in a given organ. The dose coefficients from organizations such as UNSCEAR, BEIR and ICRP can be expressed relative to absorbed doses or relative to equivalent or effective doses.

The concept of effective dose was developed by the ICRP in order to manage exposures relative to dose limits applicable to all exposures of an individual, regardless of the type of radiation (exposure of all or part of the body to various types of external radiations and to incorporated radionuclides).

Although the effective dose is not sufficient to evaluate health risk precisely, in particular the probability of cancer occurrence, it can be used in first intention to estimate an order of magnitude of the risk.
ICRP Publication 60 estimates the excess deaths from cancer to be 4% per sievert for adults subjected to low or moderate radioexposure and/or a low dose rate (in the case of chronic exposure). The UNSCEAR's 2006 report estimates the whole-life risk of death by solid cancer to be 4.3-7.2% per sievert and that of death by leukemia to be 0.6-1% per sievert.

**TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS:**

On the basis of this data, the Working Group considers that, as a first approximation, an excess of deaths by cancer of 5% per sievert can be used to evaluate the global carcinogenic risk at doses exceeding 100 mSv.

A more precise estimation of individual radio-induced cancer risk, based on committed doses in tissue and/or organs, requires expert assistance. Estimations can be based on risk coefficients published by international organizations (UNSCEAR, BEIR) and in epidemiological study reports. For this type of evaluation, it can be opportune to take uncertainties into account during dose assessment (see Topic C-4-4).

<table>
<thead>
<tr>
<th>Number</th>
<th>Literature references</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2/17*-2/32*-2/34*-2/36* – 85</td>
<td>4*</td>
</tr>
</tbody>
</table>

R. 67 | How do we evaluate the risk of stochastic effects? (GRADE A)

The effective dose is not sufficient to evaluate health risk precisely, in particular the probability of cancer occurrence. However, as a means of estimating the global carcinogenic risk approximately, we can assume a 5% excess of deaths by cancer per sievert.

To assess the stochastic risk in different organs more finely, the absorbed doses and/or the equivalent doses received by organs and tissue must be evaluated. This must be done specifically for the worker concerned by adapting the biokinetic and dosimetric hypotheses.

The individual stochastic risk will be assessed by experts, applying risk coefficients based on experimental and human experience. These risk coefficients must, if possible, be adapted to the gender and age of the individual.

Depending on the case, other factors may need to be considered, in particular health and medical history, individual susceptibility or co-exposures (other exposures to environmental and professional carcinogenic agents).

D-1-2-2 | Evaluating the risk of deterministic effects

**INTERNATIONAL RECOMMENDATIONS AND REPORT**

**ICRP 103 [2-17; 2007]**

The ICRP defines protection variables (equivalent doses and effective doses) to determine dose limits and thereby ensure that the occurrence of stochastic health effects is maintained at an acceptable level and that tissular reactions are avoided.

(156) “In retrospective assessments of doses to specified individuals that may substantially exceed dose limits, effective dose can provide a first approximate measure of the overall detriment. If radiation dose and risk need to be assessed in a more accurate way, further specific estimates of organ or tissue doses are necessary, especially if organ-specific risks for the specified individuals are needed. [...]”

(158) “The use of effective dose is inappropriate for the assessment of tissue reactions. In such situations it is necessary to estimate absorbed dose and to take into account the appropriate RBE as the basis for any assessment of radiation effects.”

(105) “[...] For such purposes, doses should be evaluated in terms of absorbed dose (in gray, Gy), and
where high-LET radiations (e.g., neutrons or alpha particles) are involved, an absorbed dose, weighted with an appropriate RBE, should be used.”

(A69) “[…] In general, fractionated doses or protracted doses at low dose rate are less damaging than are acute doses.”

<table>
<thead>
<tr>
<th>TISSUE AND EFFECT</th>
<th>THRESHOLDS FOR TISSULAR EFFECTS (IN GRAY)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dose total received during a single brief exposure</td>
</tr>
<tr>
<td>Testes:</td>
<td>0.15</td>
</tr>
<tr>
<td>Temporary sterility</td>
<td>3.5 à 6.0</td>
</tr>
<tr>
<td>Permanent sterility</td>
<td></td>
</tr>
<tr>
<td>Ovaries:</td>
<td>2.5 à 6.0</td>
</tr>
<tr>
<td>Sterility</td>
<td></td>
</tr>
<tr>
<td>Eye lens:</td>
<td>2.5 à 6.0</td>
</tr>
<tr>
<td>Detectable opacities</td>
<td></td>
</tr>
<tr>
<td>Visual impairment (cataract)</td>
<td></td>
</tr>
<tr>
<td>Bone marrow:</td>
<td>0.5</td>
</tr>
<tr>
<td>Depression of haematopoiesis</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE N°17. ESTIMATIONS OF THRESHOLDS FOR TISSULAR EFFECTS ON TESTICLES, OVARIES, EYE LENS AND BONE MARROW IN HUMAN ADULTS.**
(taken from table A.3.1 of ICRP Publication 103).

**IARC [2-36; 2001] MONOGRAPH ON THE EVALUATION OF CARCINOGENIC RISKS TO HUMANS, VOL. 78, IONIZING RADIATION, PART 2: SOME INTERNALLY DEPOSITED RADIONUCLIDES.**
This report by the International Agency for Research on Cancer includes a literature review on deterministic effects revealed after external and internal radiocontamination in man and animals. Effects have been observed in various organs:

- **Bone**
The first effects were described in female workers applying paint containing radium 226 and 228 to luminous clock faces (the contamination was mainly due to their habit of wetting the paint brush on the lips). In addition to stochastic effects (bone cancer), these workers suffered osteonecrosis and bone fractures. The subjacent histological lesions have been described extensively in animal studies on mice and dogs after contamination by alpha emitters (radium 224, thorium 227, plutonium 238 and 239) with a threshold of about 1 Gray. Such lesions have also been found in man after injection of plutonium 239 and in one case of accidental contamination by americium 241 resulting in an estimated bone activity of 500 kBq eleven years after the incident. Similar effects have also been observed in dogs after injection of beta emitters (Sr-90/Y-90).

- **Teeth**
Clock face painters contaminated by radium 226
and young subjects having received radium 224 injections (osteoarticular tuberculosis treatment) suffered fragilisation then loss of teeth. This effect is also observed in dogs and mice after administration of radium 226 and 224 and plutonium 239. In mice, the lesions appeared after radium 224 injections exceeding 16 kBq.

– **Eye**

Cataracts have been observed in female workers contaminated by radium 226 and in subjects receiving radium 224 injections (with a threshold in incorporated activity of 0.5 MBq/kg).

– **Skin**

Effects on skin have been reported after external contamination by alpha- and beta-emitting radionuclides. In particular, dermatological lesions were observed in workers cleaning up the Chernobyl accident site and, to a lesser degree, in inhabitants of the Marshall Islands exposed to nuclear fallout rich in beta emitters.

– **Liver**

Deterministic hepatic lesions have been closely studied in patients receiving Thorotrast, a colloidal preparation of Th-232 O₂ used as a contrast medium. In a Japanese population, the appearance of cirrhosis was observed for a dose rate in the liver between 0.15 and 0.6 Gray/year with an average cumulated dose of 9.5 Gray. Different types of deterministic hepatic lesions have been described in animals after administration of plutonium 239 and 238 and americium 241 and beta emitters (cerium 144).

– **Bone marrow**

Depression of haematopoiesis has been observed in patients taking Thorotrast or radium 224 and in one worker at the Hanford site heavily contaminated by americium 241. In animals, a hypoplasia of the different hematopoietic lineages is observed after administration of alpha emitters (plutonium 239, americium 241, radium 226) and beta emitters (tritium, strontium 90, phosphorus 32).

– **Gonads**

Experimental animal studies have revealed reduced ovarian volume and depressed folliculogenesis in females after injection of ¹H₂O. In males, a reduction of testicular mass has been observed after administration of ¹H₂O and americium 241.

– **Lungs**

Deterministic pulmonary lesions have been observed after autopsy in a female patient taking Thorotrast resulting in an estimated dose of 2.5 Gray in the bronchiole cells. Some animal studies describe such lesions after administration of alpha emitters (plutonium 239, americium 241) and beta emitters (strontium 90, cerium 144).

– **Thyroid**

Most effects reported (dysthyroidism, nodules) concern exposure during childhood. In adults, oral administration of iodine 131 for hyperthyroidism treatment with doses in the thyroid of 2 to 8 Gray resulted in recovery of normal thyroid activity, but led to hypothyroidism in about 26% of patients within 7 years.

In cases of exposure to a high dose that might lead to deterministic effects (in addition to stochastic ones), the risk assessment of these deterministic effects [2-17 (§158)].
effects is based on the absorbed doses weighted by the appropriate RBEs. These doses must be estimated specifically for the worker concerned by adapting the biokinetic and dosimetric hypotheses. For this type of evaluation, it may be opportune to take into consideration the uncertainties during dose assessment (see Topic C-3-4).

This individual evaluation is based on published studies, while taking into account the radionuclides responsible for the contamination.

By way of example, the tables below show the doses absorbed in target organs for a given effective dose. In both cases, these are committed doses over 50 years calculated using the IMBA software (HPA-UK). These values, using the ICRP models, apply in theory to the Reference Man. As part of an expert investigation for a given individual, the model parameters can be modified to adapt to special cases.

**TABLE N°18. DOSE ABSORBED IN THE TARGET ORGAN FOR A GIVEN EFFECTIVE DOSE.**

Effective dose and absorbed dose in lungs and bone marrow contaminated by plutonium 239 inhalation (absorption type S, AMAD 5 micrometers)

<table>
<thead>
<tr>
<th>EFFECTIVE DOSE (mSv)</th>
<th>INHALED ACTIVITY (Bq)</th>
<th>ABSORBED DOSE IN LUNGS (mGy)</th>
<th>ABSORBED DOSE IN BONE MARROW (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>11.9</td>
<td>0.0280</td>
<td>0.00269</td>
</tr>
<tr>
<td>1</td>
<td>119</td>
<td>0.280</td>
<td>0.0269</td>
</tr>
<tr>
<td>5</td>
<td>595</td>
<td>1.4</td>
<td>0.1345</td>
</tr>
<tr>
<td>20</td>
<td>2,380</td>
<td>5.6</td>
<td>0.538</td>
</tr>
<tr>
<td>50</td>
<td>5,950</td>
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<td>1.345</td>
</tr>
<tr>
<td>100</td>
<td>11,900</td>
<td>28</td>
<td>2.69</td>
</tr>
</tbody>
</table>

Effective dose and absorbed dose in the thyroid contaminated by iodine 131 inhalation (absorption type F, AMAD 5 micrometers)

<table>
<thead>
<tr>
<th>EFFECTIVE DOSE (mSv)</th>
<th>INHALED ACTIVITY (Bq)</th>
<th>ABSORBED DOSE IN THYROID (mGy)</th>
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<tr>
<td>0.1</td>
<td>9.50 E+03</td>
<td>2.0</td>
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<tr>
<td>1</td>
<td>9.50 E+04</td>
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<td>5</td>
<td>4.75 E+05</td>
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<td>20</td>
<td>1.90 E+06</td>
<td>397</td>
</tr>
<tr>
<td>50</td>
<td>4.75 E+06</td>
<td>992</td>
</tr>
<tr>
<td>100</td>
<td>9.50 E+06</td>
<td>1,985</td>
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</table>

Experts must evaluate the risk of deterministic effects on the basis of the absorbed dose in the organ/tissue, taking into account the spread over time of the doses received after internal contamination.

**R. 68 | How do we evaluate the risk of deterministic effects? (GRADE A)**
Q. How do we explain to workers the health implications of their assessed dose?

**REGULATIONS**

Several laws and regulations specific to the nuclear industry, notably the so-called Nuclear Transparency Law dated 4/03/2002 (JO 05/03/2002), and Nuclear Safety Authority documents (scale of radioprotection events), oblige company managers to analyse the slightest difference between what is expected and what actually happens. Without implying any criticism of these regulations, it is certain that this scrupulous primary prevention attitude engenders considerable anxiety among workers involved in radiological incidents.

**FRENCH PUBLIC HEALTH CODE IN FORCE ON 31/12/2010: ARTICLES L1111-1 AND L1110-4**

“People’s recognized rights are accompanied by responsibilities in order to guarantee the durability of the healthcare system and the principles on which it is founded.”

**PENAL CODE IN FORCE ON 31/12/2010: ARTICLES 226-13 AND 14**

“The revelation of secret information by a trustee holding it either due to his status (doctor, priest,…) or profession (banker, lawyer,…), or as part of a temporary function or mission, is punishable by one year of imprisonment and a fine of 15,000 euros.”

“Article 226-13 is not applicable in cases where the law imposes or authorizes the revelation of the secret.”

**TO CONCLUDE, THE WORKING GROUP HAS RULED ON THE FOLLOWING POINTS AND MAKES THE FOLLOWING RECOMMENDATIONS:**

The societal context tends to dramatize industrial and nuclear risks. The press amplifies this dramatization, influencing the viewpoint of nuclear workers’ family and social and professional circles and exacerbating their anxiety.

The occupational health practitioner must take into account the multiple influences (social context, media, family circle) on the worker’s perception of his situation in order to give him the information he expects.

More than in other circumstances, the employee’s confidence in the occupational health practitioner is fundamental to counterbalance external influences which are often negative.

It is important to underline that an internal radiocontamination always has very particular impact: despite the concept of effective dose introduced to place internal dosimetry and external dosimetry at the same level, internal exposure always engenders greater anxiety than external exposure.

The following elements must be taken in account:

– mental perception of “incorporated” contamination, which is seen as a violation that remains present after the event, sometimes for many years,

– anxiety, not always expressed verbally, about a risk of contamination of family and friends,

– notion of committed effective dose over 50 years,

It may appear surprising to mention the psychological, sociological and mediatic aspects in a technical document relating to internal radioexposure monitoring. Yet in view of the particular public perception of nuclear risks, occupational health practitioners are obliged to take into account the effects and influences, sometimes contradictory, on the risks perceived by workers in NIs. Practitioners must give workers objective information to help them understand the real level of risk to which they are exposed.

How do we explain to workers that doses received, often less than the regulatory limits, have no health consequence, when they can see for themselves that:

– investigations are being conducted, either in-house (nuclear safety services, health and safety committees, etc.) or by the nuclear authorities,

– hierarchy is anxious,

– events they have experienced are reported in the local and even the national press?

The health occupational practitioners’ role is sometimes delicate.
- complexity of the dose assessment and the numerous associated uncertainties

**DIAGRAM N°11. FACTORS INFLUENCING WORKERS’ PERCEPTION OF RISKS.**
When informing workers of their results and dose assessment, the occupational health practitioner must appreciate the psychological impact of this announcement.

It is important to underline that the practitioner is alone in this situation due to his obligation of professional secrecy.

The general presentation of the radiological risk should be adapted to the worker’s level of understanding and the emotional impact of the preliminary information.

Even in the absence of incidents, a good level of information must be maintained by:
- employee training and/or periodic information about workplace risk prevention, in association with the Radiation Protection Officer (RPO), and about biological effects of radiation, available treatments, and the like,
- presentation of systematic and special monitoring protocols to managers, preventionists, personnel representatives, and workers,
- CHSCT presentation of final statistical dosimetric report, at least once per year.

Following a contamination event or the discovery of positive measurement, it is necessary to:
- inform the worker of his results as they come in, when repeated checks are prescribed;
- explain repeated measurements by the need to increase the dose assessment precision rather than suggesting uncertainty, which is a source of anxiety;
- explain the dose assessment approach;
- separate regulatory aspects (effective dose) from health risks (absorbed dose);
- propose psychological counselling, if need be.

The local medical team is the main contact for workers and other interested parties.

When informing workers of their results and dose assessment, the occupational health practitioner must appreciate the psychological impact of this announcement.

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- employee training and/or periodic information about workplace risk prevention, in association with the Radiation Protection Officer (RPO), and about biological effects of radiation, available treatments, and the like,
- presentation of systematic and special monitoring protocols to managers, preventionists, personnel representatives, and workers,
- CHSCT presentation of final statistical dosimetric report, at least once per year.

Following a contamination event or the discovery of positive measurement, it is necessary to:
- inform the worker of his results as they come in, when repeated checks are prescribed;
- explain repeated measurements by the need to increase the dose assessment precision rather than suggesting uncertainty, which is a source of anxiety;
- explain the dose assessment approach;
- separate regulatory aspects (effective dose) from health risks (absorbed dose);
- propose psychological counselling, if need be.

The local medical team is the main contact for workers and other interested parties.
APPENDICES.
APPENDIX 1 / WORKING GROUPS COMPOSITION AND PARTICIPANTS

PROMOTERS

PRINCIPAL PROMOTER

French Occupational Health Medicine Society (SFMT: Société Française de Médecine du Travail)
President: Prof. Patrick Brochard until 2010, then Prof. Catherine Nisse

JOINT PROMOTERS

Doctors responsible for coordinating occupational health services in nuclear industries:

AREVA
Dr. Alain Acker (Medical director)
CEA
Dr. François Pic (Medical coordinator)
EDF
Dr. Dominique Folliot (Coordinating medical officer)
SPRA
Prof. Pierre Laroche (Deputy Director of the French Army Radiological Protection Service)

WORKING GROUP

GROUP COORDINATION

M. Philippe Bérard
CEA/Fontenay Aux Roses - Life Sciences
Department - Expert
Dr. Nicolas Blanchin
CEA/Cadarache - Occupational health practitioner
Dr. Michèle Gonin
EDF Saint-Denis - Nuclear Production - Occupational Health Medical Advisor
Dr. Benoit Quesne
AREVA and CEA/Marcoule - Occupational health practitioner

GROUP COMPOSITION

Health practitioner
Dr. Anne-Laure Agrinier (CEA/Marcoule),
Dr. Laurent Bourgaut (CEA/Saclay)
Pharmaceutical biologist
M. Robert Fottorino (CEA / Cadarache)
Experts
IRSN - Paris: Eric Blanchardon, Dr. Cécile Challeton de Vathaire, Didier Franck
CEA - Fontenay Aux Roses: Jean Piechowski
CEA - DAM: Paul Fritsch, Jean-Luc Poncy

READING GROUP

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Occupational health practitioner
AREVA Châlon
Dr. Stéphane Henry
Occupational health practitioner
AREVA Paris
Philippe Corrèze
Pharmaceutical biologist
AREVA The Hague
Bernadette Peleau
Pharmaceutical biologist
AREVA The Hague
### APPENDIX 1 / WORKING GROUPS COMPOSITION AND PARTICIPANTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Profession</th>
<th>Organization</th>
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<tbody>
<tr>
<td>Jean-Jacques Radecki</td>
<td>Radiation protection expert</td>
<td>AREVA Pierrelatte</td>
</tr>
<tr>
<td>Dr. Marie Luce Llaona</td>
<td>Occupational health practitioner</td>
<td>AREVA Pierrelatte</td>
</tr>
<tr>
<td>Dr. Françoise André</td>
<td>Occupational health practitioner</td>
<td>CEA DAM</td>
</tr>
<tr>
<td>Dr. Mario Annicchiarico</td>
<td>Occupational health practitioner</td>
<td>CEA Cadarache</td>
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<tr>
<td>Eric Ansoborlo</td>
<td>Chemical engineer - Expert</td>
<td>CEA Marcoule</td>
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<tr>
<td>Didier Cavadore</td>
<td>Pharmaceutical biologist</td>
<td>CEA Cadarache</td>
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<tr>
<td>Dr. Philippe Donikian</td>
<td>Occupational health practitioner</td>
<td>AMT Marcoule</td>
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<tr>
<td>Dr. Louise Grappin</td>
<td>Occupational health practitioner</td>
<td>CEA Cadarache</td>
</tr>
<tr>
<td>Gilles Hoffman</td>
<td>Employee representative</td>
<td>CEA Cadarache</td>
</tr>
<tr>
<td>Didier Kimmel</td>
<td>Nuclear testing centre director</td>
<td>CEA Cadarache</td>
</tr>
<tr>
<td>Dr. Laurence Lebaron Jacobs</td>
<td>Researcher</td>
<td>CEA Cadarache</td>
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<tr>
<td>Maurice Mazière</td>
<td>Nuclear testing centre director</td>
<td>CEA Saclay</td>
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<tr>
<td>Dr. Patrick Raynaud</td>
<td>Occupational health practitioner</td>
<td>CEA Marcoule</td>
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<td>Dr. Francis Salle</td>
<td>Occupational health practitioner</td>
<td>CEA FAR</td>
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<tr>
<td>Gonzague Abela</td>
<td>Radiation protection officer</td>
<td>EDF Saint-Denis</td>
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<tr>
<td>Dr. Catherine Bailloeuil</td>
<td>Occupational health practitioner</td>
<td>EDF Tricastin</td>
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<tr>
<td>Dr. Dider Chevalier</td>
<td>Occupational health practitioner</td>
<td>EDF Gravelines</td>
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<tr>
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<td>EDF Cattenom</td>
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<tr>
<td>Dr. Eric Laporte</td>
<td>Occupational health practitioner</td>
<td>EDF Saint-Alban</td>
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<tr>
<td>Dr. Isabelle Le Couteulx</td>
<td>Occupational health practitioner</td>
<td>EDF Paluel</td>
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<tr>
<td>Dr. Frédérique Levray</td>
<td>Occupational health practitioner</td>
<td>EDF Dampierre</td>
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<tr>
<td>Dr. Marie Laure Renouard</td>
<td>Occupational health practitioner</td>
<td>EDF Nogent</td>
</tr>
<tr>
<td>Dr. Jean-Christophe Amabile</td>
<td>Occupational health practitioner, senior in the SPRA medical division</td>
<td>EDF Tricastin</td>
</tr>
<tr>
<td>Sandra Bohand</td>
<td>Military pharmacist</td>
<td>French Army Radiological Protection Service (SPRA)</td>
</tr>
<tr>
<td>Dr. Xavier Castagnet</td>
<td>Occupational health practitioner, senior in a squadron of attack submarines</td>
<td>French Army Radiological Protection Service (SPRA)</td>
</tr>
<tr>
<td>Alain Cazoulat</td>
<td>Military pharmacist</td>
<td>French Institute for Radiological Protection and Nuclear Safety (IRSN) (retired)</td>
</tr>
<tr>
<td>Dr. Xavier Michel</td>
<td>Occupational health practitioners, deputy heads of the SPRA Medical Radioprotection Office</td>
<td>IRSN Cadarache</td>
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<tr>
<td>Dr. Franck Rivière</td>
<td></td>
<td>French Nuclear Safety Authority (ASN)</td>
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<tr>
<td>Patrice Boisson</td>
<td>Pharmaceutical biologist</td>
<td>French National Research and Safety Institute (INRS)</td>
</tr>
<tr>
<td>Alain Biau</td>
<td>Scientific evaluation manager</td>
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</tr>
<tr>
<td>François Paquet</td>
<td>Programme coordinator</td>
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<tr>
<td>Laurent Kueny</td>
<td>Chief engineer</td>
<td></td>
</tr>
<tr>
<td>Dr. Christine Gauron</td>
<td>Expert doctor</td>
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APPENDIX 1 / WORKING GROUPS COMPOSITION AND PARTICIPANTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christian Hurtgen</td>
<td>Laboratory manager</td>
<td>Belgium</td>
</tr>
<tr>
<td>Prof. Jean Claude Artus</td>
<td>Professor in nuclear medicine</td>
<td>Nimes university hospital</td>
</tr>
<tr>
<td>Prof. Dominique Choudat</td>
<td>Professor in occupational health medicine - qualified in pneumology</td>
<td>Cochin university hospital - Paris</td>
</tr>
<tr>
<td>Dr. Denis Jean Gambini</td>
<td>Radiation protection coordinator at Paris Hospital Group</td>
<td>Georges Pompidou European Hospital, Paris</td>
</tr>
</tbody>
</table>

ACKNOWLEDGEMENTS

The Writing Group member wish to thank all of the participants listed above for their particular contributions during the preparation of this report.

They also thank Mrs. Karine Petitprez, project leader at HAS, for her attentive support throughout this work.

Finally, they thank Dr. Alain Miele, occupational health practitioner, now retired, who initiated this project and was the first convenor of this Working Group.
APPENDIX 2 / READING
GROUP RESULTS

BREAKDOWN OF THE GENERAL APPRECIATION
In the scoring matrix, the scores range from 1 meaning for “in complete disagreement” to 9 meaning “in full agreement”.

| READER'S SCORES (COMBINING 3 OPINIONS PER RECOMMENDATIONS) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    |
| ALL 4 TOPICS | 17   | 24   | 72   | 91   | 312  | 380  | 881  | 2,401| 10,664|
| 0.11% | 0.16% | 0.49% | 0.61% | 2.10% | 2.56% | 5.94% | 16.18% | 71.85% |

1 Total number of replies for the scoring level of all of the recommendations and the 3 opinions
2 Percentage of all replies

ANALYSIS BY TYPE OF OPINION
In the scoring matrix, the scores range from 1 meaning for “in complete disagreement” to 9 meaning “in full agreement”.

<table>
<thead>
<tr>
<th>TOPIC A</th>
<th>SCORE (17 RECOMMENDATIONS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
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<tr>
<td>Relevance/Justification</td>
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</tr>
<tr>
<td>0.15%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Clarity and presentation/</td>
<td>0</td>
</tr>
<tr>
<td>Legibility</td>
<td>0.00%</td>
</tr>
<tr>
<td>Application faisability</td>
<td>1</td>
</tr>
<tr>
<td>0.15%</td>
<td>0.00%</td>
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<tr>
<td>All opinions included</td>
<td>2</td>
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<tr>
<td>0.10%</td>
<td>0.00%</td>
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1 Total number of replies for the scoring of the 17 recommendations for each type of opinion
2 Percentage of all replies
# APPENDIX 2 / READING GROUP RESULTS

## TOPIC C 
**SCORE (59 RECOMMENDATIONS)**

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<th>4</th>
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<th>6</th>
<th>7</th>
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</tr>
</thead>
<tbody>
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<td>65</td>
<td>144</td>
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<td>Application faisability</td>
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1 Total number of replies for the scoring of the 59 recommendations for each type of opinion  
2 Percentage of all replies

## TOPIC B 
**SCORE (59 RECOMMENDATIONS)**

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<tr>
<td>Application faisability</td>
<td>4</td>
<td>3</td>
<td>11</td>
<td>16</td>
<td>59</td>
<td>87</td>
<td>193</td>
<td>353</td>
<td>1,581</td>
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<tr>
<td>All opinions included</td>
<td>8</td>
<td>10</td>
<td>31</td>
<td>37</td>
<td>142</td>
<td>181</td>
<td>412</td>
<td>1,092</td>
<td>5,008</td>
</tr>
</tbody>
</table>

1 Total number of replies for the scoring of the 59 recommendations for each type of opinion  
2 Percentage of all replies

## TOPIC B 
**SCORE (42 RECOMMENDATIONS)**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevance/Justification</td>
<td>0</td>
<td>3</td>
<td>10</td>
<td>5</td>
<td>11</td>
<td>15</td>
<td>58</td>
<td>299</td>
<td>1,192</td>
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<tr>
<td>Clarity and presentation/Legibility</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>10</td>
<td>38</td>
<td>40</td>
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<td>Application faisability</td>
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<td>10</td>
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<td>25</td>
<td>82</td>
<td>119</td>
<td>289</td>
<td>896</td>
<td>3,353</td>
</tr>
</tbody>
</table>

1 Total number of replies for the scoring of the 42 recommendations for each type of opinion  
2 Percentage of all replies
**APPENDIX 2 / READING GROUP RESULTS**

<table>
<thead>
<tr>
<th>TOPIC D</th>
<th>SCORE (10 RECOMMENDATIONS) *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td>Relevance/Justification</td>
<td>1</td>
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<tr>
<td></td>
<td>0.27%</td>
</tr>
<tr>
<td>Clarity and presentation/</td>
<td></td>
</tr>
<tr>
<td>Legibility</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.27%</td>
</tr>
<tr>
<td>Application feasibility</td>
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</tr>
<tr>
<td></td>
<td>0.55%</td>
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<tr>
<td>All opinions included</td>
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</tr>
<tr>
<td></td>
<td>0.36%</td>
</tr>
</tbody>
</table>

* Of which some were transferred to subject A
1 Total number of replies for the scoring of the 10 recommendations for each type of opinion
2 Percentage of all replies
Reminder:
The literature search was supplemented by a keyword search using “AND” combinations of keywords on MEDLINE.

The tables below list the number of references identified and the number selected for each subject and keyword combination.

The exclusion criteria of the references are:
- date for articles in the targeted search: prior to 2005,
- place: exclusion of articles concerning exposures outside NIs,
- language: only articles in English and in French were used,
- radionuclide: exclusion of articles concerning radionuclides not selected for the guide (see recommendation limits),
- exclusion of articles concerning expertise and without interest for practical application.

### SEARCH FOR A BASELINE DIRECTLY APPLICABLE IN PROFESSIONAL PRACTICE

<table>
<thead>
<tr>
<th>KEYWORDS</th>
<th>REFERENCES IDENTIFIED</th>
<th>REFERENCES SELECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal dose - Workers - Guidebook - Guide - Handbook</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Internal dose - Occupational - Guidebook - Guide - Handbook</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Internal dose - Medical - Guidebook - Guide - Handbook</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Internal dose - Assessment - Radionuclide - Guide</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Internal dose - Assessment - Guide</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Internal dose - Guide</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Internal dose - NPP</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

This search reveals the absence of a baseline directly applicable in professional practice.
SEARCH FOR MONITORING PROGRAMMES: TOPICS B-1 TO B-3 OF THE RECOMMENDATIONS

<table>
<thead>
<tr>
<th>KEYWORDS SEARCH “AND” COMBINATIONS FOR THE FOLLOWING KEYWORDS</th>
<th>REFERENCES IDENTIFIED</th>
<th>REFERENCES SELECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal dose – Radionuclide – Occupational – Nuclear</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Internal dose – Workers – Monitoring – Program</td>
<td>5</td>
<td>4 including 1 duplicate</td>
</tr>
<tr>
<td>Internal dose – Medical – Radionuclide – Monitoring</td>
<td>20</td>
<td>7 including 4 duplicates</td>
</tr>
<tr>
<td>Internal dose – Radionuclide – Monitoring</td>
<td>41</td>
<td>10 including 7 duplicate</td>
</tr>
<tr>
<td>Internal dose – Workers – Monitoring – Routine</td>
<td>5</td>
<td>3 including 1 duplicate</td>
</tr>
<tr>
<td>Internal dose – Medical – Radionuclide – Routine Monitoring</td>
<td>1</td>
<td>1 including 1 duplicate</td>
</tr>
<tr>
<td>Internal dose – Assessment – Monitoring – Routine</td>
<td>8</td>
<td>6 including 3 duplicates</td>
</tr>
<tr>
<td>Internal dose – Assessment – Monitoring – Workers</td>
<td>5</td>
<td>4 including 2 duplicates</td>
</tr>
<tr>
<td>Internal dose – Assessment – Monitoring – Workers – Routine</td>
<td>3</td>
<td>3 including 3 duplicates</td>
</tr>
<tr>
<td>Internal dose – Medical – Radionuclide – Special monitoring</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Internal dose – Workers – Monitoring – Special</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Internal dose – Workers – Monitoring – Acute</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

TARGETED SEARCH BY EXPERTS AND PRACTITIONERS IN THEIR FIELD OF EXPERTISE

21 *

TOTAL

48 REFERENCES SELECTED

## APPENDIX 3 / DOCUMENTARY
SEARCH RESULTS

### SEARCH FOR LABORATORY TESTS: TOPIC B-4 OF THE RECOMMENDATIONS

<table>
<thead>
<tr>
<th>KEYWORDS</th>
<th>REFERENCES IDENTIFIED</th>
<th>REFERENCES SELECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal dose - Bioassay - <em>In vivo</em></td>
<td>13</td>
<td>10 including 6 duplicates</td>
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<tr>
<td>Internal dose - Bioassay - <em>In vitro</em></td>
<td>12</td>
<td>6 including 6 duplicates</td>
</tr>
<tr>
<td>Detection limit - Thyroid - Monitoring</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Detection limit - Thyroid - Iodine</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Decision threshold - Urine</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Decision threshold - Feces</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Decision threshold - Whole body</td>
<td>4</td>
<td>0</td>
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<tr>
<td>Decision threshold - Lung</td>
<td>27</td>
<td>0</td>
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<tr>
<td>Decision threshold -</td>
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<td>0</td>
</tr>
<tr>
<td>Detection limit - Faeces</td>
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<td>0</td>
</tr>
<tr>
<td>Detection limit - Whole body - Monitoring</td>
<td>10</td>
<td>0</td>
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<tr>
<td>Detection limit - Lung - Monitoring - Radiation</td>
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<td>1</td>
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<tr>
<td>Internal dose - Bioassay - Detection limit</td>
<td>1</td>
<td>0</td>
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<tr>
<td>Bioassay - Detection limit - <em>In vitro</em></td>
<td>10</td>
<td>0</td>
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<tr>
<td>Bioassay - Detection limit - Urine</td>
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<td>2</td>
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<tr>
<td>Nasal swab - Dose</td>
<td>11</td>
<td>2 including 1 duplicate</td>
</tr>
<tr>
<td>Nasal swab - Sample</td>
<td>30</td>
<td>2 duplicates</td>
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<tr>
<td>Local wound - Retention</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Local wound - Dose - Activity</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Local wound - Activity - Medical</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td><strong>TARGETED SEARCH BY EXPERTS AND PRACTITIONERS</strong></td>
<td><strong>7</strong></td>
<td><strong>7</strong></td>
</tr>
<tr>
<td><strong>IN THEIR FIELD OF EXPERTISE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>15 REFERENCES SELECTED</strong></td>
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</table>


196
SEARCH FOR THE CHOICE OF THE MODEL AND PARAMETERS: TOPIC C-1 OF THE RECOMMENDATIONS

<table>
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<th>REFERENCES IDENTIFIED</th>
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<tbody>
<tr>
<td>Interpretation bioassay - Default parameters</td>
<td>2</td>
<td>6</td>
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<tr>
<td>Interpretation bioassay - Model - Biokinetic</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Interpretation bioassay - Model - Dosimetric</td>
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<td>1 including 1 duplicate</td>
</tr>
<tr>
<td>Interpretation bioassay - Model - Dose</td>
<td>15</td>
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</tr>
<tr>
<td>Interpretation bioassay - Software</td>
<td>10</td>
<td>9 including 3 duplicates</td>
</tr>
<tr>
<td>Interpretation bioassay - Tool</td>
<td>6</td>
<td>5 including 5 duplicates</td>
</tr>
<tr>
<td>Interpretation bioassay - Mixture</td>
<td>3</td>
<td>1 including 1 duplicate</td>
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<tr>
<td>Interpretation bioassay - Intake - Pathway</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Interpretation bioassay - Intake - Time</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>Interpretation bioassay - Amad</td>
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<tr>
<td>Interpretation bioassay - Parameter</td>
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</table>

TARGETED SEARCH BY EXPERTS AND PRACTITIONERS IN THEIR FIELD OF EXPERTISE

10 *

TOTAL

32 REFERENCES SELECTED

SEARCH FOR ESTIMATION OF INTAKE AND DOSE: TOPIC C-3 OF THE RECOMMENDATIONS

<table>
<thead>
<tr>
<th>KEYWORD SEARCH</th>
<th>REFERENCES IDENTIFIED</th>
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</thead>
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<td>7</td>
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<td>Interpretation bioassay - Rapid</td>
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<tr>
<td>Interpretation bioassay - Magnitude</td>
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<td>0</td>
</tr>
<tr>
<td>Minimum dose detectable - Internal</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Minimum dose detectable - Bioassay</td>
<td>4</td>
<td>2 including 2 duplicates</td>
</tr>
<tr>
<td>Natural excretion - Radionuclide</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>Interpretation bioassay - Treatment</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Internal dose - Treatment - DTPA</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Internal dose - Treatment - Iodine stable</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Internal dose - Treatment - Water tritium</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Reconstruction dose - Treatment - DTPA</td>
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<td>Reconstruction dose - Treatment - Iodine</td>
<td>8</td>
<td>1 including 1 duplicate</td>
</tr>
<tr>
<td>Dose Treatment - Prussian blue</td>
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<td>0</td>
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<tr>
<td>Interpretation bioassays - Dose - Assessment</td>
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<td>0</td>
</tr>
<tr>
<td>Interpretation bioassay - Dose - Assessment</td>
<td>37</td>
<td>13 including 4 duplicates</td>
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<tr>
<td><strong>TARGETED SEARCH BY EXPERTS AND PRACTITIONERS IN THEIR FIELD OF EXPERTISE</strong></td>
<td></td>
<td>16 *</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>37 REFERENCES SELECTED</td>
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[3-9-17-24-26-30*-46*-53*-59-70*-73-75-76-78*-79*-80*-82-83*-89*-99-102*-105-106-107-115*-120*-121-130*-131-133-134-143-145*-151-155*-159-164*]
### APPENDIX 3 / DOCUMENTARY SEARCH RESULTS

#### SEARCH FOR CONSISTENCY: TOPIC C-4 OF THE RECOMMENDATIONS

<table>
<thead>
<tr>
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<th>References Selected</th>
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<tbody>
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<td>16</td>
<td>2</td>
</tr>
<tr>
<td>Dose consistency - Working place</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Dose consistency - Initial data</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Dose consistency - Multiple data</td>
<td>15</td>
<td>1 including 1 duplicate</td>
</tr>
<tr>
<td>Dose consistency - Best estimate</td>
<td>27</td>
<td>1 including 1 duplicate</td>
</tr>
<tr>
<td>Dose best estimate - Intake - Internal</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>Dose assessment - Individual - Internal - Measurement</td>
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<td>10 including 1 duplicate</td>
</tr>
</tbody>
</table>

**Targeted Search by Experts and Practitioners in their Field of Expertise**  
2 *

**Total**  
22 References Selected

APPENDIX 3 / DOCUMENTARY
SEARCH RESULTS

SEARCH FOR UNCERTAINTIES: TOPIC C-4-5 OF THE RECOMMENDATIONS

<table>
<thead>
<tr>
<th>KEYWORD SEARCH “AND” COMBINATIONS OF THE FOLLOWING KEYWORDS</th>
<th>REFERENCES IDENTIFIED</th>
<th>REFERENCES SELECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose assessment - Uncertainties - Internal - Workers</td>
<td>7</td>
<td>7 including 1 duplicate</td>
</tr>
<tr>
<td>Dose assessment - Uncertainties - Internal - Estimate</td>
<td>9</td>
<td>3 including 1 duplicate</td>
</tr>
</tbody>
</table>

TARGETED SEARCH BY EXPERTS AND PRACTITIONERS IN THEIR FIELD OF EXPERTISE

28 *

TOTAL

36 REFERENCES SELECTED

[4*-8*-15*-20-26-40*-41*-47*-48-56*-62*-71*-77*-84*-85-86*-87*-88-91-96*-121*-122*-123*-124*-129*-130*-133*-138-139*-142*-149*-152-164*-168*-170*-174*]

SEARCH FOR OTHER DOSIMETRIC APPROACHES: TOPIC C-5 OF THE RECOMMENDATIONS

<table>
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<th>KEYWORD SEARCH “AND” COMBINATIONS OF THE FOLLOWING KEYWORDS</th>
<th>REFERENCES IDENTIFIED</th>
<th>REFERENCES SELECTED</th>
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</thead>
<tbody>
<tr>
<td>Dose assessment - Deconvolution</td>
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</tr>
<tr>
<td>Dose assessment - Other approaches</td>
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<td>3</td>
</tr>
</tbody>
</table>

TARGETED SEARCH BY EXPERTS AND PRACTITIONERS IN THEIR FIELD OF EXPERTISE

0 *

TOTAL

3 REFERENCES SELECTED

[145-146-147]
ACUTE INHALATION OF COBALT 60 IN A SOURCE PREPARATION INSTALLATION

Case no.3 of the IDEAS/IAEA intercomparison exercise (Hurtgen and al 2006 - 98). The data is generated artificially.

DESCRIPTION

The workplace is an installation where cobalt cables irradiated by neutrons (at about 300°- 400°C) in a nuclear reactor are used to prepare sealed Co-60 sources. The contaminated worker is a 35-year-old man weighing 70 kg.

An irradiated capsule containing 900 TBq of Co-60 cables, in the form of metal and/or oxide, was opened in a hot cell, then after 10 minutes, the alarms were heard. The operators closed the source, donned protective clothing and respirators, stopped the leak and decontaminated the work zone.

A special monitoring programme by urinary and whole body measurements was started, with the workers excluded from the contaminated zone.

The air monitoring data indicates an increase in air contamination of 500 RAC (reference air concentration); a figure of 40 RAC corresponds for the operator to an event of significant level. External contamination by Co-60 was revealed by the RPO then confirmed by the occupational health service.
APPENDIX 4 / DOSE ASSESSMENT EXAMPLES

MEASUREMENT RESULTS

Whole body counting (WBC)

<table>
<thead>
<tr>
<th>TIME AFTER EVENT (DAYS)</th>
<th>WHOLE BODY ACTIVITY IN Co-60 (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>day of the event</td>
<td>3.50 E+05</td>
</tr>
<tr>
<td>3</td>
<td>5.90 E+04</td>
</tr>
<tr>
<td>10</td>
<td>2.39 E+04</td>
</tr>
<tr>
<td>14</td>
<td>2.92 E+04</td>
</tr>
<tr>
<td>17</td>
<td>2.01 E+04</td>
</tr>
<tr>
<td>20</td>
<td>1.82 E+04</td>
</tr>
<tr>
<td>27</td>
<td>2.16 E+04</td>
</tr>
<tr>
<td>40</td>
<td>1.98 E+04</td>
</tr>
<tr>
<td>60</td>
<td>2.16 E+04</td>
</tr>
<tr>
<td>80</td>
<td>1.75 E+04</td>
</tr>
<tr>
<td>190</td>
<td>1.16 E+04</td>
</tr>
</tbody>
</table>

Urinary radiotoxicology

<table>
<thead>
<tr>
<th>TIME AFTER EVENT (DAYS)</th>
<th>URINARY EXCRETION DAILY IN Co-60 (Bq/DAY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>day of the event (spot sample)</td>
<td>6.80 E+03</td>
</tr>
<tr>
<td>3</td>
<td>9.81 E+02</td>
</tr>
<tr>
<td>10</td>
<td>2.55 E+02</td>
</tr>
<tr>
<td>14</td>
<td>7.09 E+02</td>
</tr>
<tr>
<td>27</td>
<td>6.40 E+01</td>
</tr>
<tr>
<td>40</td>
<td>7.10 E+01</td>
</tr>
<tr>
<td>60</td>
<td>3.70 E+01</td>
</tr>
<tr>
<td>80</td>
<td>2.90 E+01</td>
</tr>
<tr>
<td>190</td>
<td>1.10 E+01</td>
</tr>
</tbody>
</table>

The results of faecal radiotoxicology are not given in this example.
APPLICATION OF THE GUIDELINES

Initial grading of the event

R20: The air data given by the RPO indicates a significant event.

R47 and R48: The early measurement results are:
WBC at D0: 3.5E+05 Bq greater than DRL = 1.5E+04 Bq
urine at D0: 6.8E+03 Bq/day greater than DRL = 1.6E+02 Bq/day

R24: This justifies the initial grading of the event at a significant level and the creation of a special monitoring protocol by radiotoxicological urinary and faecal analyses and whole-body measurements, with exclusion of risk.

R47 and R48: The examination results at D3 and D10 are:
WBC at D3: 5.90E+04 Bq greater than DRL = 1.5E+04 Bq
urine at D3: 9.81E+02 Bq/day greater than DRL = 1.6E+02 Bq/day
WBC at D10: 2.39E+04 Bq greater than DRL = 3.8E+03 Bq
urine at D10: 2.55E+02 Bq/day greater than DRL = 1.6E+01 Bq/day

which justifies the assessment of a committed effective dose.

Assessment of incorporated activity and committed effective dose *

<table>
<thead>
<tr>
<th>TIME AFTER EVENT (DAYS)</th>
<th>WHOLE BODY ACTIVITY IN Co-60 M(T) (BQ)</th>
<th>RETENTION FUNCTION F(T) (BQ / BQ INHALED)</th>
<th>INTAKE A: m(t) / f(t) (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5.90 E+04</td>
<td>1.52 E-01</td>
<td>3.88 E+05</td>
</tr>
<tr>
<td>10</td>
<td>2.39 E+04</td>
<td>7.19 E-02</td>
<td>3.32 E+05</td>
</tr>
<tr>
<td>14</td>
<td>2.92 E+04</td>
<td>6.63 E-02</td>
<td>4.40 E+05</td>
</tr>
<tr>
<td>17</td>
<td>2.01 E+04</td>
<td>6.30 E-02</td>
<td>3.19 E+05</td>
</tr>
<tr>
<td>20</td>
<td>1.82 E+04</td>
<td>6.01 E-02</td>
<td>3.03 E+05</td>
</tr>
<tr>
<td>27</td>
<td>2.16 E+04</td>
<td>5.48 E-02</td>
<td>3.94 E+05</td>
</tr>
<tr>
<td>40</td>
<td>1.98 E+04</td>
<td>4.77 E-02</td>
<td>4.15 E+05</td>
</tr>
<tr>
<td>60</td>
<td>2.16 E+04</td>
<td>4.03 E-02</td>
<td>5.36 E+05</td>
</tr>
<tr>
<td>80</td>
<td>1.75 E+04</td>
<td>3.50 E-02</td>
<td>5.00 E+05</td>
</tr>
<tr>
<td>190</td>
<td>1.16 E+04</td>
<td>1.97 E-02</td>
<td>5.89 E+05</td>
</tr>
</tbody>
</table>

* R36, R39 and R41: with the default model: inhalation, ICRP models with AMAD of 5 micrometers and absorption type M according to table 3.3 of the Appendix of the Decree dated 1/9/2003 for “unspecified compound”
R50 and R51: The geometric mean of the estimations $A_i$ is $3.50 \times 10^5$ Bq. The dose coefficient for this intake route and this model is $7.1 \times 10^{-9}$ Sv/Bq. The committed effective dose is therefore estimated to be:

$$3.50 \times 10^5 \times 7.1 \times 10^{-9} = 2.48 \times 10^{-3} \text{ Sv} = 2.5 \text{ mSv}.$$
ACUTE INHALATION OF TRANSURANIC ELEMENTS INCLUDING PU-238

A real case reported by N. Blanchin and al (2008 – reference 24)

DESCRIPTION

A production operator was transferring sludges of plutonium oxide stored for many years in the “materials store” for purposes of repackaging. He was wearing cotton overalls without respiratory protection. When removing a pot from a storage location, he noticed that the double vinyl envelope was severely disintegrated. He put the sludge in a transfer container and continued his work. One or two minutes later, an air contamination of 100 DACL\(^*\) and 27 DACL\(^*\).h was detected by a monitoring device (EDGAR type) located about 3 meters from the operator who immediately left the cell.

A radioprotection inspection revealed surface contamination on the right hand of 15 Bq of alpha activity which disappeared without difficulty at the first wash. There was no other trace of external contamination. A nasal mucus sample revealed 3.2 Bq (alpha) activity confirmed by a nose-blows whose activity was 1.9 Bq (alpha).

In application of the protocols established by the occupational health service, a half-ampule of DTPA (500 mg) was injected intravenously one hour after the incident. The operator was sent to the Laboratory for a lung measurement. The first count was 22 Bq of Am-241 (counting carried out after a shower and change of clothes). Urine and faecal analyses were prescribed.

The isotopic composition of the alpha-emitting transuranics handled by the operator was Am-241 (30%), Pu-238 (50%), Pu-239 (10%) and Pu-240 (10%), corresponding approximately to the composition found in the worker’s stools.

\(^*\) DACL = derived air concentration limit
MEASUREMENT RESULTS

Lung measurements of Am-241

<table>
<thead>
<tr>
<th>DAY</th>
<th>GEOMETRY</th>
<th>ACTIVITY (Bq)</th>
<th>UNCERTAINTY (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>lung</td>
<td>22 Bq</td>
<td>9 Bq</td>
</tr>
<tr>
<td>1</td>
<td>lung with lead screen</td>
<td>&lt; 14 Bq</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>basi-thoracic</td>
<td>21 Bq *</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>lung</td>
<td>&lt; 14 Bq</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>lung</td>
<td>86 Bq *</td>
<td></td>
</tr>
</tbody>
</table>

* indicative measurement (the “lung” geometry was not respected)

Urinary radiotoxicology

<table>
<thead>
<tr>
<th>DAY</th>
<th>Am-241</th>
<th>Pu-238</th>
<th>Pu-239-240</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Activity Bq/day</td>
<td>Uncertainty Bq/day</td>
<td>Activity Bq/day</td>
</tr>
<tr>
<td>0 *</td>
<td>2.5 E-03</td>
<td>4 E-04</td>
<td>0.6 E-03</td>
</tr>
<tr>
<td>3</td>
<td>5.2 E-03</td>
<td>6 E-04</td>
<td>2.8 E-03</td>
</tr>
<tr>
<td>10</td>
<td>2.3 E-03</td>
<td>4 E-04</td>
<td>1.2 E-03</td>
</tr>
<tr>
<td>17</td>
<td>4.0 E-04</td>
<td>9 E-05</td>
<td>2.0 E-04</td>
</tr>
<tr>
<td>33</td>
<td>&lt; 3.0 E-04</td>
<td>&lt; 2.0 E-04</td>
<td>&lt; 2.0 E-04</td>
</tr>
<tr>
<td>39</td>
<td>&lt; 2.0 E-04</td>
<td>&lt; 1.0 E-04</td>
<td>&lt; 1.0 E-04</td>
</tr>
<tr>
<td>52</td>
<td>&lt; 2.0 E-04</td>
<td>&lt; 1.0 E-04</td>
<td>&lt; 1.0 E-04</td>
</tr>
</tbody>
</table>

* urine at 16 hours
### Faecal radiotoxicology

<table>
<thead>
<tr>
<th>DAY</th>
<th>Am-241 Activity Bq/day</th>
<th>Am-241 Uncertainty Bq/day</th>
<th>Pu-238 Activity Bq/day</th>
<th>Pu-238 Uncertainty Bq/day</th>
<th>Pu-239-240 Activity Bq/day</th>
<th>Pu-239-240 Uncertainty Bq/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.34 E-02</td>
<td>2 E-03</td>
<td>1.79 E-02</td>
<td>2 E-04</td>
<td>1.23 E-02</td>
<td>1.4 E-03</td>
</tr>
<tr>
<td>1</td>
<td>3.34 E-02</td>
<td>2 E-03</td>
<td>1.79 E-02</td>
<td>2 E-04</td>
<td>1.23 E-02</td>
<td>1.4 E-03</td>
</tr>
<tr>
<td>10</td>
<td>1.6 E-03</td>
<td>5 E-04</td>
<td>1.0 E-03</td>
<td>4 E-04</td>
<td>7.0 E-04</td>
<td>2.4 E-04</td>
</tr>
<tr>
<td>17 *</td>
<td>&lt; 9.0 E-04</td>
<td>&lt; 6.0 E-04</td>
<td>&lt; 3.0 E-04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>&lt; 7.0 E-04</td>
<td>&lt; 3.0 E-04</td>
<td>&lt; 2.0 E-04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>&lt; 7.0 E-04</td>
<td>&lt; 7.0 E-04</td>
<td>&lt; 6.0 E-04</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* low ash weight: 0.7g

### APPLICATION OF THE GUIDELINES

**Initial grading of the event**

R20: The significant air contamination rise (27 DACL.h.), the existence of measured alpha activity on the nasal mucus sample and the Am-241 lung measurement initial exceeding the detection limit classify this incident at a significant level.

R47 and R48: The early measurements results are (the plutonium oxide is assumed to be of type S):

- Lung Am-241 at D0: 22 Bq greater than DRL = 9 mBq
- Urine Pu-238-239-240 at D0: 1.3 mBq/day greater than DRL = 0.1 mBq/day
- Faeces Pu-238-239-240 at D0: 30.2 mBq/day less than DRL = 10 Bq/day

R24: This justifies the initial grading of the event at significant level and the creation of a special monitoring protocol by radiotoxicological urinary and faecal analyses and lung measurements, with exclusion of risk.

R47 and R48: The results at D3 and D10 are:

- Urine Pu-238-239-240 at D3: 5.5 mBq/day greater than DRL = 0.1 mBq/day
- Faeces Pu-238-239-240 at D1: 30.2 mBq/day less than DRL = 10 Bq/day
Assessment of intake and committed effective dose

R40: The intake and committed effective doses corresponding to each radionuclide are calculated separately with the specific model. In this example, only the intake and effective committed dose relative to Pu-238 are estimated.

The significant air contamination rise captured by a detector far from the person not wearing a filtering respirator, the existence of measured activity on the nasal mucus sample, as well as the initial lung measurement point to an inhalation mechanism. The low corporal contamination on healthy skin, the rapid local decontamination and the exposure to an aerosol form eliminate the possibility of percutaneous intake.

R36, R39 and R41: With the default model: inhalation, ICRP models with AMAD of 5 micrometers and absorption type S according to table 3.3 of the Appendix of the Decree dated 1/9/2003 for “insoluble oxides”.

<table>
<thead>
<tr>
<th>TIME AFTER EVENT (DAYS)</th>
<th>DAILY URINARY EXCRETION PU-238 (Bq/DAY)</th>
<th>EXCRETION FUNCTION F(T) (Bq / Bq INHALED)</th>
<th>INTAKE A_t = m(t) / f(t) (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2.8 E-03</td>
<td>8.3 E-07</td>
<td>3,400</td>
</tr>
<tr>
<td>10</td>
<td>1.2 E-03</td>
<td>2.2 E-07</td>
<td>5,500</td>
</tr>
<tr>
<td>17</td>
<td>2.0 E-04</td>
<td>1.8 E-07</td>
<td>1,100</td>
</tr>
</tbody>
</table>
R50 and R51: The geometric mean of the estimations $A_i$ is 87 Bq. The dose coefficient for this intake route and this model is $1.1 \times 10^{-5}$ Sv/Bq. The committed effective dose is therefore estimated to be $87 \times 1.1 \times 10^{-5} = 0.96$ mSv.

R52: The measurement results having dropped below the detection limit after one month of monitoring, we can validate the final value of the dose assessment, on condition that all of the assessments of intake based on the examination results are consistent with each other.

R64: The assessments of intake based on urine or faeces are clearly inconsistent, differing by a factor at least one thousand. The dose cannot therefore be validated here.

R65: We must therefore call into question at least the validity of each analysis result, the influence of the DTPA therapy and the choice of the absorption type S.
TRACEABILITY SHEET FOR CASES OF POSITIVE SYSTEMATIC ANALYSIS

A | WORKER IDENTIFICATION:

NAME: .........................  FORENAME: .........................
EMPLOYER: ........................
DATE OF BIRTH: ../../....
AGE: ..... YEARS  WEIGHT: ..... kg  HEIGHT: ..... cm

B | PRESUMED EXPOSURE CIRCUMSTANCES:

PERIOD OF EXPOSURE: FROM ../../.... TO ../../....
PLACE OF EXPOSURE: EXTERIOR  □  INTERIOR  □  BUILDING N°: .....;
ROOM N°: .....;
SUSPECTED INTAKE ROUTE: INHALATION - WOUND - OTHER:

C | RADIOCONTAMINANT:

RADIONUCLIDE:  /  /  /  /  
MIXTURE: YES  □  NO  □
PHYSICAL FORM: GAS  □  VAPOUR  □  AEROSOLS  □  DUST  □
ABSORPTION TYPE:  □  TYPE F  □  TYPE M  □  TYPE S
DEFAULT AMAD: YES  □  NO  □
IF NO: AMAD = ..... µm  DENSITY: ..... g cm⁻³

D | FIRST MEASUREMENT RESULTS:

1/ URINE: SPOT  □  24-HOUR URINE  □

<table>
<thead>
<tr>
<th>DATE OF RECEIPT</th>
<th>RN</th>
<th>RESULT</th>
<th>YES</th>
<th>NO</th>
<th>NO</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
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</tr>
</tbody>
</table>

UNITS: µg  □  Bq  □  MBq  □  PER DAY  □  PER SAMPLE  □
## APPENDIX 5 / TRACEABILITY SHEET MODELS

### 2/ FAECES: 24-HOUR FAECES □ OTHER □

<table>
<thead>
<tr>
<th>DATE OF RECEIPT</th>
<th>RN</th>
<th>RESULT</th>
<th>YES</th>
<th>NO</th>
<th>SELECTED FOR INTAKE</th>
<th>COMMENT</th>
</tr>
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<tbody>
<tr>
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<td></td>
</tr>
</tbody>
</table>

**UNITS:** μg □, Bq □, MBq □ PER DAY □ PER SAMPLE □

### 3/ IN VIVO MEASUREMENT: NaI DETECTOR □ Ge(HP) DETECTOR □

<table>
<thead>
<tr>
<th>DATE OF MEASUREMENT</th>
<th>RNI</th>
<th>RESULT</th>
<th>&lt; DL</th>
<th>RN2</th>
<th>RESULT</th>
<th>&lt; DL</th>
<th>SELECTED FOR INTAKE</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

**UNITS:** Bq □

### E | PRESCRIPTION OF CONTROL TESTS:

<table>
<thead>
<tr>
<th>1/ URINE: NO □ YES □</th>
<th>DATES:</th>
<th>PRIOR EXCLUSION: NO □ YES □</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/ FAECES: NO □ YES □</td>
<td>DATES:</td>
<td>PRIOR EXCLUSION: NO □ YES □</td>
</tr>
<tr>
<td>3/ IN VIVO: NO □ YES □</td>
<td>DATES:</td>
<td>PRIOR EXCLUSION: NO □ YES □</td>
</tr>
</tbody>
</table>
APPENDIX 5 / TRACEABILITY SHEET MODELS

F | RESULTS OF CONTROL TESTS:

URINE: SPOT ☐ 24-HOUR URINE ☐

<table>
<thead>
<tr>
<th>DATE OF RECEIPT</th>
<th>RN</th>
<th>RESULT</th>
<th>EXCLUSION FROM ZONE</th>
<th>SELECTED FOR INTAKE CALCULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
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</tr>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

UNITS: μg ☐ βq ☐ mBq ☐ PER DAY ☐ PER SAMPLE ☐

FAECES: 24-HOUR FAECES ☐ OTHER ☐

<table>
<thead>
<tr>
<th>DATE OF RECEIPT</th>
<th>RN</th>
<th>RESULT</th>
<th>EXCLUSION FROM ZONE</th>
<th>SELECTED FOR INTAKE CALCULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
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</tr>
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<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

UNITS: μg ☐ βq ☐ mBq ☐ PER DAY ☐ PER SAMPLE ☐

G | DOSIMETRIC INTERPRETATION:

1/ RADIOISOTOPE:
2/ BIOKINETIC MODEL: ICRP PUBLICATION 54 ☐ ICRP PUBLICATION 78 ☐ OTHER ☐
3/ PHYSICOCHEMICAL PARAMETERS:

<table>
<thead>
<tr>
<th>INTAKE DAY</th>
<th>BY DEFAULT</th>
<th>SPECIFIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>INHALATION</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>AMAD</th>
<th>5 micrometers</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSORPTION TYPE</td>
<td></td>
</tr>
</tbody>
</table>
4/ DOSE PER UNIT INTAKE:

<table>
<thead>
<tr>
<th>ISOTOPE OR MIXTURE</th>
<th>E(50)</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sv Bq$^{-1}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sv Bq$^{-1}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sv Bq$^{-1}$</td>
</tr>
</tbody>
</table>

5/ USE OF SOFTWARE: NO ☐ YES ☐ WHICH:

H | DOSE ASSESSMENT RESULT:

1/ CALCULATION: NO ☐ YES ☐
2/ DOSE: LESS THAN THE RL ☐ GREATER THAN THE RL ☐ DOSE:
3/ COMMUNICATION OF THE RESULT:
   EMPLOYEE: NO ☐ YES ☐
   EMPLOYER AND/OR RPO: NO ☐ YES ☐
   IRSN: NO ☐ YES ☐

I | DOSE ASSESSMENT RESPONSIBILITIES:

1/ PRACTITIONER IN CHARGE:
2/ PRACTITIONER (REVIEWER):
3/ EXPERT VALIDATING THE ASSESSMENT:
<table>
<thead>
<tr>
<th>A</th>
<th>WORKER IDENTIFICATION:</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAME: .................</td>
<td>FORENAME: ...............</td>
</tr>
<tr>
<td>EMPLOYER: ..............</td>
<td></td>
</tr>
<tr>
<td>DATE OF BIRTH: ../..../..</td>
<td></td>
</tr>
<tr>
<td>AGE: ..... YEARS</td>
<td>WEIGHT: ..... kg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B</th>
<th>CIRCUMSTANCES OF EXPOSURE:</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE OF THE EVENT: ../..../..</td>
<td></td>
</tr>
<tr>
<td>DURATION OF EXPOSURE: START TIME: ..h..mn</td>
<td>END TIME: ..h..mn</td>
</tr>
<tr>
<td>PLACE OF EXPOSURE: EXTERIOR ☐</td>
<td>INTERIOR ☐</td>
</tr>
<tr>
<td>ROOM N°: .....</td>
<td></td>
</tr>
<tr>
<td>SUSPECTED INTAKE ROUTE: INHALATION - WOUND - OTHER</td>
<td></td>
</tr>
<tr>
<td>ATMOSPHERIC EXPOSURE: NO ☐</td>
<td>YES ☐</td>
</tr>
<tr>
<td>IF YES, NUMBER OR RAC:</td>
<td></td>
</tr>
<tr>
<td>RADIOPROTECTION: MASK WORN? YES ☐</td>
<td>NO ☐</td>
</tr>
<tr>
<td>CORPORAL CONTAMINATION: SITE: LEVEL (Bq/cm²):</td>
<td></td>
</tr>
<tr>
<td>ASSOCIATED MEDICAL ELEMENTS (WOUND - BURN - INJURY...):</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C</th>
<th>RADIOCONTAMINANT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>RADIONUCLIDE: / / /</td>
<td></td>
</tr>
<tr>
<td>MIXTURE: YES ☐</td>
<td>NO ☐</td>
</tr>
<tr>
<td>PHYSICAL FORM: GAS ☐</td>
<td>VAPOUR ☐</td>
</tr>
<tr>
<td>ABSORPTION TYPE: TYPE F ☐</td>
<td>TYPE M ☐</td>
</tr>
<tr>
<td>DEFAULT PARTICLE SIZE: YES ☐</td>
<td>NO ☐</td>
</tr>
<tr>
<td>IF NO: AMAD = ..... µm</td>
<td>DENSITY: ..... g cm⁻³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>D</th>
<th>TREATMENT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>THERAPY CONDUCTED: YES ☐</td>
<td>NO ☐</td>
</tr>
<tr>
<td>IF YES, WHICH:</td>
<td></td>
</tr>
<tr>
<td>IF YES: THERAPY STARTED ON ../..../.. AT ..h..mn</td>
<td></td>
</tr>
<tr>
<td>POSOLOGY: ......g OR ..... AMPULE</td>
<td></td>
</tr>
<tr>
<td>BY ORAL ROUTE ☐</td>
<td>INHALATION ☐</td>
</tr>
</tbody>
</table>
E | FIRST MEASUREMENTS RESULTS:

1/ NASAL MUCUS SAMPLE: SWAPS □ FLGS □ 
SAMPLED ON .../.../....: NEGATIVE
  POSITIVE FOR ALPHA □ VALUE Bq
  FOR BETA □
  FOR GAMMA □

2/ LOCAL MEASUREMENT:
SAMPLED ON .../.../....: NEGATIVE
  POSITIVE FOR ALPHA □ VALUE Bq
  FOR BETA □
  FOR GAMMA □

3/ IN VIVO MEASUREMENTS TESTS: NaI DETECTOR □ Ge(HP) DETECTOR □

<table>
<thead>
<tr>
<th>DATE OF MEASUREMENT</th>
<th>RN1 RESULT</th>
<th>&lt; DL</th>
<th>RN2 RESULT</th>
<th>&lt; DL</th>
<th>NO</th>
<th>COMMENT</th>
</tr>
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<tbody>
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</tbody>
</table>

UNITs: Bq □

F | PRESCRIPTION OF RADIOTOXICOLOGICAL TESTS:

1/ URINE: NO □ YES □ DATES:
2/ FAECES: NO □ YES □ DATES:
3/ OTHER: NO □ YES □ DATES:
## Appendix 5 / Traceability Sheet Models

**G | Individual Monitoring Data:**

### 1/ In Vivo Measurements: NaI Detector □ Ge(HP) Detector □

<table>
<thead>
<tr>
<th>DATE OF MEASUREMENT</th>
<th>RN1 RESULT</th>
<th>&lt; DL</th>
<th>RN2 RESULT</th>
<th>&lt; DL</th>
<th>SELECTED FOR INTAKE</th>
<th>CALCULATION</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td>NO</td>
<td>COMMENT</td>
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</table>

Units: Bq □

### Urine:

<table>
<thead>
<tr>
<th>DATE OF RECEIPT</th>
<th>RN</th>
<th>RESULT</th>
<th>TREATMENT TAKEN INTO ACCOUNT</th>
<th>SELECTED FOR INTAKE</th>
<th>CALCULATION</th>
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<td></td>
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<td>COMMENT</td>
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</table>

Units: μg □ Bq □ mBq □ PER DAY □ PER SAMPLE □

### Faeces:

<table>
<thead>
<tr>
<th>DATE OF RECEIPT</th>
<th>RN</th>
<th>ASH WEIGHT</th>
<th>RESULT</th>
<th>&lt; DL</th>
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<th>CALCULATION</th>
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<tr>
<td></td>
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<td>NO</td>
<td>COMMENT</td>
</tr>
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</table>

Units: μg □ Bq □ mBq □ PER DAY □ PER SAMPLE □
H | DOSIMETRIC INTERPRETATION:

1/ RADIOISOTOPE: 
2/ BIOKINETIC MODEL: ICRP PUBLICATION 54 □ ICRP PUBLICATION 78 □ OTHER □
3/ PHYSICOCHEMICAL PARAMETERS:

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<tr>
<td>INTAKE DAY</td>
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<tr>
<td>INTAKE ROUTE</td>
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<td>INHALATION</td>
</tr>
<tr>
<td>AMAD</td>
<td></td>
<td>5 micrometers</td>
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<tr>
<td>ABSORPTION TYPE</td>
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</table>

4/ DOSE PER UNIT INTAKE:

<table>
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<th>ISOTOPES OR MIXTURE</th>
<th>E(50)</th>
<th>UNIT</th>
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<tr>
<td></td>
<td></td>
<td>Sv Be⁻¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sv Be⁻¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sv Be⁻¹</td>
</tr>
</tbody>
</table>

5/ USE OF SOFTWARE: NO □ YES □ WHICH:

I | DOSE ASSESSMENT RESULT:

1/ CALCULATION: NO □ YES □
2/ DOSE: LESS THAN THE RL □ GREATER THAN THE RL □ DOSE:
3/ COMMUNICATION OF THE RESULT:
   EMPLOYEE: NO □ YES □
   EMPLOYER AND/OR RPO: NO □ YES □
   IRSN: NO □ YES □

J | DOSE ASSESSMENT RESPONSABILITIES:

1/ PRACTITIONER IN CHARGE:
2/ PRACTITIONER (REVIEWER):
3/ EXPERT VALIDATING THE ASSESSMENT:
LETTER TO IRSN: INTERNAL DOSE FOR RECORDING IN THE SISERI DATABASE

Recipient                                      I.R.S.N.  

Object: Internal dose for recording  
in the SISERI database  

You will find below data concerning the recording  
of an internal committed effective dose in the national  
database SISERI. This dose was received following an event  
on <date>  
in the company <name>:  

Name:  
  Forename:  
  Social Security no.:  
  Date of birth:  
  Company:  
  Date:  
  Effective dose:  

Copy: occupational health practitioner of the person concerned.
Dear Sir,

Following the radiotoxicological measurements prescribed after the event on XX/XX/XXXX that occurred in the installation X of the company X at the X site, I write to inform you that a committed effective dose for an internal exposure to ionizing radiation has been recorded in your medical file.

The dose chosen is X mSv of committed effective dose over 50 years.

The radionuclides in question are: xx and xx in their chemical form xx.

This dose will be recorded for the month of X 20xx. It must be added to your operational dose over the 12 month period preceding the event (between X xxxx and X xxxx), which is less than X mSv. The sum of the two doses X mSv may be compared with the annual regulatory limit of 20 mSv.

The effective dose limit has not therefore been exceeded over the 12 month period.

In a separate letter, I have informed the radiation protection officer of x and your company X, in compliance with Article R4456-23 of the French Labor Code. I am also informing the IRSN in order that this dose be recorded for you in the national database (SISERI).

I remain at your disposal for any additional information.

Yours faithfully,

Dr. X
Occupational health practitioner of X

Copy: Dr. X (for information + medical file of the person concerned)

Ref: Decree dated 30 December 2004 relating to the individual medical follow-up card and to individual dosage information for workers exposed to ionizing radiation.
LETTER TO EMPLOYER: INDIVIDUAL INTERNAL DOSE INFORMATION

Recipient: Director of the Establishment X

M. Director,

In order to enable you to declare the event that occurred on XXXX/XXXX to the Nuclear Safety Authority in compliance with Article R4455-7 of the French Labor Code, I inform you that an internal committed effective dose was recorded for the month of X 2xxxx in the medical file of M. X, an employee of the company X.

This dose must be added to the external dose of the previous twelve month period up until the event (between X xxxx and X xxxx) which is less than X mSv (operational dose to which you have access; Article R4453-27 of the Labor Code).

The sum of the two doses does not exceed the effective dose limit over the 12 month period (20 mSv), but it does exceed one quarter of this limit.

I have informed the employee concerned of this today. I am informing Dr. X, the occupational health practitioner, and the radiation protection officer of X and of the company X.

This internal dose is reported to the IRSN for update of the national database SISERI.

I remain at your disposal for any additional information.

Yours faithfully,

Dr. X
Occupational health practitioner of X
LETTER TO WORKER: ZERO DOSE INFORMATION

Recipient
Worker

INDIVIDUAL INTERNAL DOSE RESULTS

Enterprise:

On the basis of the radiotoxicological measurements over the last 12 months on the site of x, I inform you that there is no requirement to include in your medical file any committed effective dose concerning an internal exposure to ionizing radiation.

Dr. ...... .

Ref: Decree dated 30 December 2004 relating to the individual medical follow-up card and to individual dosage information for workers exposed to ionizing radiation.
LETTER TO WORKER: DOSE TO BE RECORDED

On the basis of the results of the radiotoxicological measurements prescribed after the event on __/__/_____ that occurred in the installation ______________ of the company ______________ at the site x, I inform you that a committed effective dose concerning an internal exposure to ionizing radiation has been noted in your medical file.

The dose assessed is ________ mSv which can be compared with the regulatory annual limit of 20 mSv.

The radionuclides in question are:

I remain at your disposal for any additional information.

Yours faithfully.

Dr. ...... .
Occupational health practitioner

Copy: medical file of the person concerned

Ref: Decree dated 30 December 2004 relating to the individual medical follow-up card and to individual dosage information for workers exposed to ionizing radiation.
In compliance with Article R4453-28 of the French Labor Code and on the basis of the results of the radiotoxicological measurements prescribed after the event that occurred on XX/XX/XXXX in the installation of X of the company X, I inform you that an internal committed effective dose was recorded in the medical file of M. X.

The dose chosen is X of committed effective dose over 50 years.

The radionuclides in question are: xx and xx in their chemical form xx.

This dose will be recorded for the month of X 20xx. It must be added to the external dose over the 12 month period preceding the event (between X and X xxxx) which is X (operational dose). The sum of the two doses may be compared with the annual regulatory limit of 20 mSv.

The effective dose limit has not therefore been exceeded over the 12 month period.

I have informed the person concerned today. I am also informing Dr. X, his occupational health practitioner.

This internal dose is reported to the IRSN for update of the SISERI database.

I remain at your disposal.

Yours sincerely,

Dr. X
Occupational health practitioner of X
Criteria to guide the selection of software can be defined. The WG has not evaluated the software according to these criteria owing to the commercial nature of most of them. In addition, other criteria (price, frequency of use) specific to each user may need to be taken into account.

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>Grade</th>
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<tbody>
<tr>
<td>ICRP models</td>
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<tr>
<td>Monitoring data with its associated uncertainties</td>
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<td>Information relating to detection limits of the results</td>
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<td>Sampling type and frequency</td>
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<td>Chronic / Acute intake</td>
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<tr>
<td>Intake route: inhalation, ingestion and percutaneous</td>
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<td>Influence of medical treatment</td>
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<tr>
<td>Chronic</td>
<td>Optional</td>
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<td>Half-interval method</td>
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<td>Traceability in the medical file</td>
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<td>Handling of large data volumes</td>
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<td>Intake</td>
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<td>Effective dose assessments</td>
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<td>Data specific to the workplace</td>
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<td>Validation by intercomparison exercises</td>
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<td>Adaptation to regulatory evolutions</td>
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<tr>
<td>Ease of use</td>
<td>Optional</td>
</tr>
</tbody>
</table>
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The prevention of risks relating to exposure to ionizing radiation is governed by legislative and regulatory measures derived from France’s Public Health Code and Labor Code.


1.2 Labor Code – Decree dated 1 September 2003 defining the methods of calculating committed effective doses and equivalent doses resulting from exposure of people to ionizing radiation (J.O. no.262 dated 13 November 2003, p.19326)

1.3 Decree dated 20 December 2004 relating to the individual medical follow-up card and to individual dosimetric information for workers exposed to ionizing radiation

1.4 Decree 75-306 dated 28 April 75 relating to the protection of workers in nuclear installations, modified by Decree 2003-296 dated 31 March 2003

1.5 DGT/ASN Circular no.04 dated 21 April 2010 relating to prevention measures for ionizing radiation risks

1.6 Interministerial Directive dated 7 April 2005 on the action of public authorities in events leading to an emergency radiological situation (JORF no.84 dated 10 April 2005, page 6478, Text no.1)

1.7 French Public Health Code


2.4 International Commission on Radiological Protection. Individual


2.10 International Commission on Radiological Protection. The ICRP database of dose coefficients: workers and members of the public. CD-ROM version 2.01, Elsevier. 1998


2.16 International Commission on Radiological Protection. Guide for the practical applications of the ICRP Human Respiratory
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NCRP PUBLICATIONS


AIEA SAFETY GUIDES AND SERIES


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| 2.31 | International Atomic Energy Agency. Methods for Assessing Occupational Radiation Doses Due to Intakes of Radionuclides. IAEA Safety Series No. 37, Vienna. 2004 |
| 2.32 | International Atomic Energy Agency. Dosimetric and medical aspects of the radiological accident in Goiânia. AIEA-TECDOC-1009. 1987 |

### OTHER INTERNATIONAL PUBLICATIONS

| 2.34 | UNSCEAR 2000 “Sources and effects of ionizing radiation” Rapport à l’assemblée générale, avec annexes scientifiques, 2000 |
| 2.35 | BEIR VII: Health risks from exposure to low levels of ionizing radiation 2006 |

### NATIONAL PUBLICATIONS


### STANDARDS

| 3.1 | AFNOR: Professional monitoring of workers occupationally exposed to a risk of internal contamination with radioactive material (ISO 20553. 2006 standard). |
| 3.4 | Determination of the detection limit and decision threshold for ionizing radiation measurements - Part 5: Fundamental principles and their applications to counting measurements made |
on filters during accumulation of radioactivity (ISO 11929-5. 2005 standard).

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Control of the risk of exposure to alpha emitting radionuclides in french nuclear power plants: example of cattenom. Radiation protection dosimetry. Volume 105, Nº1-4, pp 303-309. 2003


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### Medical monitoring of occupational internal exposure to radionuclides in nuclear installations

### Clinical practice recommendations

**January 2012**


Improve monitoring protocols, define a committed effective dose assessment method and provide information to help evaluate the health risk related to dose.

**Professionals concerned**
- Multidisciplinary occupational health professionals
- Emergency specialists and hospital doctors

**Promoter**
- French Occupational Health Medicine Society (SFMT: Société Française de Médecine du Travail)

**Working Group**
- Dr. Anne-Laure Agrinier (CEA/Marcoule - occupational health practitioner)
- M. Philippe Bérard (CEA/Fontenay Aux Roses - expert)
- M. Eric Blanchardon (IRSN/Paris - expert)
- Dr. Nicolas Blanchin (CEA/ Cadarache - occupational health practitioner)
- Dr. Laurent Bourgaut (CEA/Saclay - occupational health practitioner)
- Dr. Cécile Challeton de Vathaire (IRSN/Paris - expert)
- M. Robert Fottorino (CEA/Cadarache - pharmaceutical biologist)
- M. Didier Franck (IRSN/Paris - expert)
- M. Paul Fritsch (CEA/DAM - expert)
- Dr. Michèle Gonin (EDF Saint-Denis - nuclear production - occupational health medical advisor)
- M. Jean Piechowski (CEA/Fontenay Aux Roses - expert)
- M. Jean-Luc Poncy (CEA/DAM - expert)
- Dr. Benoit Quesne (AREVA and CEA/Marcoule - occupational health practitioner)

**Reading Group**
- See the participants in the case statement

**Documentary search**
- January 2005 to December 2010, in addition to ICRP publications
- See the documentary search in the case statement

**Validation**
- HAS label attributed in July 2011

**Information sheets**
- Information sheets:
  - For workers exposed to radionuclides in NIs
  - Guide for emergency aid workers
Art direction and graphic conception:
Nicolas Gonin
contact@nicolasgonin.com