Medical monitoring and dosimetric uncertainty concerning actinides: experience feedback and optimisation

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The individual dosimetric surveillance of workers exposed to actinides is intended to ensure that any intake is detected at an early stage and that the associated committed doses are evaluated. The latest ICRP recommendations impose additional internal dose estimation constraints. Difficulty in interpreting the results of surveillance stem from uncertainty concerning the prospective biokinetics of inhaled particles, the actual industrial situation (different workstations and changes in employee positions in companies) as well as the surveillance regime chosen.

The authors describe their experience of the surveillance of nuclear fuel cycle workers and the optimisation of dose evaluation. The introduction of work area or workshop monitoring associated with measures to detect collective and individual exposure necessitates an exact knowledge of the actual nature of the workstations and the products handled there, and the fundamental requirement is that the means must match the risks. Collective monitoring can, for instance, be carried out by taking nose blow each time a zone is left, measuring air conditions and characterising workstations, all modes of surveillance which are as close as possible to operational dosimetry, the goal of which is to control exposure by monitoring the actual effectiveness of the radiological protection measures. Individual monitoring combines whole body counting with the monitoring of urinary and faecal excreta, to situate the case of each worker in terms of the dose limits. Three situations in very different industrial sites have thus been analysed, making it possible to substantiate the usefulness and the complementarity of the monitoring procedures adopted.

The lower dose limits imposed by the regulations necessitate reducing the factors of uncertainty so that internal doses can be more accurately estimated. The surveillance must be adapted to each individual industrial site according to the actual risks encountered in the fuel cycle, from fabrication to decommissioning of the facilities. This optimisation calls for close collaboration between the radiological protection departments, human-factors engineers and occupational medicine services involved.
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I – INTRODUCTION

The individual dosimetric surveillance of workers exposed to actinides is intended to ensure that any intake is detected at an early stage and that the associated committed doses are evaluated. The latest ICRP recommendations (1,2,3) impose additional internal dose estimation constraints. Difficulty in interpreting the results of surveillance stem from uncertainty concerning the prospective biokinetics of inhaled particles, the actual industrial situation (different workstations and changes in employee positions in companies) as well as the surveillance regime chosen.

II – PRINCIPLES BEHIND WORKER MONITORING

Medical surveillance is usually based either on in vivo measurements (whole body scanning) in association with the retention model, or on radiotoxicological analysis in association with the systemic model. However, where the alpha risk is concerned, the detection limit of certain examinations, their frequency and the uncertainties associated with measurement and interpretation make it difficult to evaluate intake rapidly. All of the above lead to uncertainties in the assessment of the internal dose received by each worker.

As far as inhalation is concerned, the respiratory tract model described in ICRP Publication 66 (4), which is the most representative, makes it possible to take into account many of the specific features of aerosols occurring at workstations, for example particle size distribution, expressed as activity mean aerodynamic diameter (AMAD) and the corresponding standard deviation ($\sigma_g$), particle density and solubility as a function of chemical form.

During regular surveillance, to set the frequency of checks, it is considered that as far as the dose calculation is concerned, repeated random intakes within a surveillance interval is equal to a single intake at the mid-point of the interval from the mathematical model point of view (3,5). When choosing the most realistic systematic surveillance period, it must be ensured that interpretation of the examinations will lead to neither underestimation nor overestimation of the results by more than a factor of 3 in relation to the most conservative intake hypothesis (intake the day after the previous negative analysis). In certain work situations (handling of actinides in confined areas) where the exposure risk is more often incidental than chronic, this approach generally leads to an overestimate.

In practice, biomedical surveillance of the actinide risk will be implemented in all work situations (incident, routine or worksite) where the exposure risk can lead to doses in excess of 1 mSv over one year. Two objectives are thus met:

From an individual point of view, it must guarantee that in all cases, intake (either one-off or chronic) reaching the derived recording level will be detected. This objective determines the operational resources implemented, the type(s) of examination, their frequency and the collection conditions (with or without exclusion).

From a collective point of view, the fact that individual analyses are spread over the year for exposed personnel means that workstations can be monitored permanently.

This type of surveillance has to be adapted to the risk of exposure to actinides by making allowance for
the actual risk of worker contamination and the analytical effectiveness of each examination. How can each worker be monitored individually to obtain an accurate picture of his internal exposure? This question led us to develop a system for monitoring exposure to alpha dust associated with the actual activity of each worker.

III – THREE EXAMPLES OF WORKER MONITORING DURING THE FUEL CYCLE (FROM MANUFACTURING TO DECOMMISSIONING OF FACILITIES)

III-1 – Fabrication of uranium fuel

This involves the creation and use of various uranium compounds. Since the process is not always implemented inside a containment, there is no absolute barrier between these compounds and the personnel. There is a wide variety of industrial compounds with different chemical properties and isotopic compositions (natural, enriched, depleted and reprocessed uranium). These factors determine the extent to which they can be transferred and their chemical and radiological toxicity. Should the facilities malfunction, atmospheric contamination may occur, *a minima*, possibly leading to internal exposure of the personnel (6). Atmospheric contamination can vary considerably from one workstation to another and at different points during the day for the same workstation; it can even vary from one team to another. The variations affect the internal contamination of an individual who, during his working day, is subject to all the events occurring at the various workstations where he finds himself.

The instauration of work area or workshop monitoring system associated with measures to detect collective and individual exposure necessitates an *exact knowledge of the actual nature of the workstations and the products handled* there, and the fundamental requirement is that the means must match the risks.

III-1-1 – Aerosols: the importance of particle size

In order to obtain more information about the specific parameters of the compounds, a study carried out by the Institute for Nuclear Safety and Protection aimed to characterise the particle size distribution in samples of uranium compounds taken from the fuel fabrication facilities of different companies, particularly COGEMA, FBFC, COMURHEX and DCC. The results are given in the table 1 and correspond to 140 AMAD measurements made on six compounds in these French fuel cycle facilities during the period from 1987 to 1995 (7).

<table>
<thead>
<tr>
<th>Uranium cycle activities:</th>
<th>French uranium cycle company</th>
<th>AMAD (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UF₄ ore processing</td>
<td>COMURHEX</td>
<td>6.8 (n=8)</td>
</tr>
<tr>
<td>Enriched fuel fabrication</td>
<td>COGEMA</td>
<td>6.1 (n=6)</td>
</tr>
<tr>
<td></td>
<td>FBFC</td>
<td>5.1 (n=109)</td>
</tr>
<tr>
<td>Uranium metal fabrication</td>
<td>SILVA process</td>
<td>Bimodal distribution (1-20% &lt; 1µm) and 7.6 µm (n=17)</td>
</tr>
<tr>
<td>Overall uranium cycle</td>
<td>Overall uranium cycle</td>
<td>5.5 (n=140)</td>
</tr>
</tbody>
</table>

n = number of measurements.

Table 1: AMAD measurements in French fuel cycle facilities

This study led to an average AMAD estimate of 5.5 µm measured at four uranium processing sites in France, with extreme values ranging from < 1 to 7.6 µm; this corresponds to the decision made by the ICRP to recommend a reference AMAD of 5 µm in Publication 66.
III-1-2 – Transferability of inhaled substances

Individual surveillance takes the form of whole body scans and monitoring of urinary and faecal excreta, making it possible to situate the worker’s situation in terms of the dose limits. Direct detection of the intake of actinides using whole body measurement is based on the detection of X photons with characteristic energy levels. However, this method offers a very poor level of sensitivity due both to the low intensity of X photons emitted and self-absorption in the tissues and to the very high level of background noise produced by the other radionuclides present. Thus, for each radionuclide considered, the detection thresholds are usually far higher than the regulatory limits. It is therefore impossible to use these methods alone in the context of medical surveillance. The choice between a monitoring procedure based on urine and one based on faecal matter depends on the transferability of the products being handled.

At the COMURHEX conversion plant, the worker monitoring system makes allowance for the physical and chemical properties of the uranium compounds (8) (yellow cake, UF₄ and natural transferable uranium). Surveillance of potential internal exposure by inhaling uranium dust is carried out using aerosol sampling devices (APA) located in each facility. They are placed in the vicinity of potential uranium dust emission points.

This workstation surveillance (measurement of atmospheric concentration, surface wipe tests etc.) complements individual surveillance since it provides useful indicators for establishing guidelines (creation of protocols) but in no way replaces analyses made on the individual himself for estimating doses. Indeed, many parameters both technical (positioning of radiological protection devices, particle size analysis of the product, density, chemical form, rheological phenomena etc.) and biomedical (activity of the subject, respiratory function etc.) account for the considerable deviations between initial estimates based on atmospheric concentration levels and the dose estimated by means of direct or indirect measurements on the subject.

Two types of method have been implemented for the individual surveillance of uranium. Systematic minimal urine surveillance, the frequency of which is calculated on the basis of the ICRP's biokinetic models which set a minimum interval of 90 days between two examinations, in other words an examination every quarter at least. Additional urine surveillance is carried out if atmospheric values are higher than usual (8).

This allows the occupational physician to monitor plant personnel more closely. Furthermore, the APA values are transmitted to each workshop, making each worker take responsibility for himself, and even creating such a sense of responsibility within the workshop. A gradual daily increase in atmospheric values still well below regulatory limits alerts the personnel who can then modify the worksite conditions and the radiological protection measures.

In UO₂ pellet fabrication plants, the risk of internal irradiation through inhalation stems from the handling of uranium oxide powders which are only slightly transferable. The aim of optimising the surveillance of workers was to improve the harmony between the various types of individual surveillance, making allowance for radiological protection objectives (workstation and individual surveillance), operating constraints and the constraints inherent in the measuring techniques.
Originally, the usual type of individual surveillance was based on measurements carried out on excreta without excluding safe workstations and on lung scans whose detection limits were too high (110 to 150 Bq) for detecting low-level contamination. A protocol was set in place to complement conventional surveillance (9). It includes whole body scanning at the end of the exposure period, carried out just before a period of leave lasting more than ten days and urinary and faecal measurements made before work is resumed, i.e. in the zone exclusion period.

This no-exposure period of at least ten days prior to the examination of faecal matter means that particles deposited in the upper airways and transiting through the oesophagus can be eliminated. It means that doses can be estimated using the results from regular faecal matter, without having to consider an exact intake date.

Moreover, it has been shown that it is important to repeat the examinations throughout the year to confirm the results, since interpretation cannot be based on a single isolated result, for example faecal elimination varies with time (a factor of 1000 is possible within a period of a few days), and it is always difficult to interpret a single result. An examination of faecal matter over the last three days of worksite operation has been requested to reduce this uncertainty.

III-2 – Monitoring of a decommissioning worksite

Over and above individual surveillance, collective surveillance can, for instance, be carried out by taking nasal smears (nose blow) each time a zone is left, by atmospheric measurements and the identification of workstations, all modes of surveillance with are as close as possible to operational dosimetry, the goal of which is to control exposure by monitoring the actual effectiveness of radiological protection measures.

At EDF, nose blow monitoring is carried out daily on decommissioning worksites to complement individual surveillance. Worksite monitoring by means of nasal mucus is perfectly compatible with operational dosimetry. It should reflect the exposure conditions of workers on the worksite and therefore make it possible to limit exposure to a level which is as low as reasonable possible, making allowance for technical and economic obligations. This method is rapid, since the results are known within 24 hours of the sample arriving at the laboratory and global (all worksite personnel or a representative sample can be monitored). In 1999, EDF’s Medical and Radiotoxicological Analysis Laboratory analysed more than 6000 nasal samples. If each worker takes this action each time he leaves a zone, the origin and date of alpha contamination can be determined and the most risky worksite operations identified. In association with radiological protection departments, the results of environmental measurements made on the worksite (swipe tests and measurements) and contamination measurements made on individuals can be compared and the radiological protection system modified if need be. Moreover, dose estimates are made on the basis of the results of systematic analysis of faecal matter.

IV- CONCLUSION

The prevention of radiological risks is based on the radiological protection principles stipulated by the ICRP. It includes risk prevention and the optimisation of radiological protection methods, making allowance for economic and social factors (ALARA “As Low As Reasonably Achievable”).

A reduction in the regulatory dose limits (1,10) would require a reduction in the uncertainty factors associated with internal dose estimates. As a result, the surveillance must be adapted to each individual industrial
site according to the actual risks encountered in the fuel cycle, from fabrication to decommissioning of the facilities. This optimisation calls for close collaboration between the radiological protection departments, human-factors engineers and occupational medicine services involved.

Bibliography


