Strategies and Methods for Optimisation of Internal Exposures of Workers from Industrial Natural Sources (SMOPIE)

J. van der Steen[1], A.W. van Weers[1], C.W.M. Timmermans[1], P.V. Shaw[2], C. Lefaure[3], J.-P. Degrange[3] and O. Witschger[4]

[1] *Nuclear Research & Consultancy Group, Arnhem, The Netherlands*
[2] *Occupational Services Department, Heath Protection Agency, Leeds, UK*
[3] *CEPN, Fontenay aux Roses, France*
[4] *Institut National de Recherche et de Sécurité, Vandoeuvre les Nancy France*

1. Abstract

Work activities with materials containing natural radionuclides (NORM) can involve significant exposure of workers, due to internal contamination by inhalation. However, there can be considerable differences in work place conditions, radionuclides involved and the physical and chemical matrices in which the radionuclides are incorporated. This project has been started following a recommendation from the third European ALARA Network workshop on “managing internal exposure” at Munich in 1999 and was funded by the European Commission in the 5th Framework Programme[1]. The project covered occupational internal exposures in various NORM industries. The study aimed to recommend monitoring strategies and methods to optimise radiation protection.

2. Objective

The objective of the study was to recommend monitoring strategies and methods for optimising internal exposure in a range of exposure situations. This was achieved by the following steps:

- to prepare a summary of number of workers in the EU that may be exposed to NORM;
- to study cases of real internal exposure situations, in co-operation with industry;
- to evaluate monitoring strategies and methods for optimisation of internal exposure situations;
- to recommend monitoring strategies and methods in the main exposure situations.

[1] contract No FIGM-CT2001-00176

A detailed assessment of exposure conditions in industrial workplace conditions (case studies) has been made, in close co-operation between the contractors and their industrial partners. This provided the basis for recommending monitoring strategies and methods for optimising internal exposure in a range of exposure situations. The industrial processes and the natural radionuclides of concern are given in Table 1.

Table 1. Industrial partners in SMOPIE.

Industry	**Process**	**Main natural radionuclides**
Thermphos International B.V. The Netherlands	Elementary phosphorus production from phosphate ore	^{210}Po, ^{210}Pb
Kerr-McGee The Netherlands	TiO_2 production from rutile	^{238}U, ^{232}Th
COMURHEX France	UF_6 production from uranium ore concentrates	^{238}U
Heavy Mineral Sands Association United Kingdom	Zircon sands processing	^{232}Th
Eavy Mineral Sands Association United Kingdom	TiO_2 production from rutile and beneficiate	^{238}U, ^{232}Th, $^{226,228}Ra$

3. Number of workers and associated dose levels

The study summarised the available information in Europe on the number of workers exposed to internal contamination and the dose levels involved. The results show that there is a severe lack of data. Several studies have been reviewed, but they do not provide the information for a scientifically sound evaluation of the problem. The scarce information indicates that there may be about 85,000 exposed workers (see Table 2). This number certainly warrants more research in this area.

Table 2. Estimates of the number of potentially exposed workers in EU NORM industries.

NORM industry and work activity	Number of exposed workers (rounded)	Basis for estimate
Thoriated electrodes, production, grinding and use	70 000	Extrapolation of Dutch and German data
Phosphate fertiliser trade and use	10 000	German data multiplied by 4
Oil and gas production, exposure to scale dust at maintenance	2 000	Based on 1000 production installations and two workers potentially exposed annually per installation
Other industries	~ 3 000	
Total (rounded)	**85 000**	

4. Monitoring strategies and methods

4.1 General considerations for dose assessments

In many studies, occupational doses from exposure to NORM have been calculated by making use of exposure scenarios and (conservative) parameter values. For accurate dose assessments, it is necessary to set up monitoring programs. Important issues are the spatial variation of airborne dust, time variation of the exposure, mobility of workers, multiple dust sources of exposure and non-uniformity of the dust composition. Personal air sampling should be preferred above static air sampling. The SMOPIE results provide a scientific and practical basis for monitoring programs, both for individual workers and for the workplace.

4.2 Aerosol characteristics, lung clearance classes and dose coefficients

For an accurate dose assessment, it is necessary to have information about the characteristics of the aerosols, in terms of AMAD and Geometric Standard Deviation (GSD), the lung clearance class of the radioactive compounds in the aerosol (F, M and S), and the dose coefficients for these compounds.

Dose coefficients for other lung clearance classes and particle sizes have been calculated for the main radionuclides belonging to the ^{238}U and ^{232}Th natural chains for a wider range of particle sizes than available from ICRP. An example is provided in Table 3 for inhalation of particles with AMAD 5 µm and GSD 2.5. From this table several important observations follow with respect to the ratios between the dose coefficients for particles with lung solubility class S and F respectively:

- The S/F ratio is high for ^{226}Ra (16) and even higher (87) for ^{226}Ra with low Rn emanation rate;
- The S/F ratio is about 10 for ^{238}U, ^{234}U and ^{228}Ra and about 4 for ^{210}Pb and ^{210}Po;
- The S/F ratio is very low for ^{232}Th and ^{230}Th;
- Dose coefficients for class S and M natural radionuclides are rather strongly AMAD dependent; those for class F are only slightly dependent on AMAD.

Special attention should be paid to NORM materials with a very low Rn emanation, since these have a much higher dose coefficient than the standard Ra compounds, for which ICRP assumes by default a high Rn emanation rate. The current ICRP biokinetic model for Ra assumes that Rn emanates very efficiently from the inhaled particle, with an escape rate of 100 d^{-1} from the respiratory tract. This means that Rn and its short-lived daughters do not contribute to the dose to the lungs, even when the particle is poorly soluble. Many NORM materials, however, show a very low Rn emanation of only a few percent. When such a particle is inhaled the emanation will not change significantly. Since a large part of the potential alpha energy of Rn and its daughters is not taken into account, the dose to the lungs is underestimated by a factor of 5 to 6.

Table 3. Workers dose inhalation coefficients (Sv/Bq) and their ratios for individual radionuclides and chain segments. AMAD 5 µm, GSD 2.5.

Nuclide, chain or chain segment	Fast	Moderate	Slow	Ratio S/F	Ratio S/M
^{238}U	5.9E-07	1.7E-06	5.7E-06	9.8	3.5
^{234}U	6.5E-07	2.1E-06	6.8E-06	10	3.2
^{230}Th	1.2E-04	2.8E-05	7.2E-06	0.06	0.26
^{226}Ra	4.4E-07	2.2E-06	6.9E-06	16	3.2
^{226}Ra *)	4.4E-07	1.4E-05	3.8E-05	87	2.8
^{210}Pb	1.1E-06	7.4E-07	4.3E-06	3.8	5.7
^{210}Po	7.3E-07	2.2E-06	2.7E-06	3.7	1.25
^{238}Usec	1.2E-04	3.7E-05	3.4E-05	0.28	0.92
^{238}Usec *)	1.2E-04	4.8E-05	6.5E-05	0.53	1.36
^{226}Ra+	2.3E-06	5.1E-06	1.4E-05	6.1	2.7
^{226}Ra+ *)	2.3E-06	1.6E-05	4.5E-05	20	2.8
*) Low Rn emanation rate					
	Fast	**Moderate**	**Slow**	**Ratio S/F**	**Ratio S/M**
^{232}Th	1.3E-04	2.9E-05	1.2E-05	0.09	0.41
^{228}Ra	1.1E-06	1.7E-06	1.1E-05	10	6.7
^{228}Th	3.4E-05	2.2E-05	2.5E-05	0.74	1.14
^{232}Thsec	1.6E-04	5.3E-05	4.9E-05	0.30	0.92

4.3 Requirements for monitoring techniques

The technical capabilities and general suitability of monitoring techniques have been considered. The monitoring strategies currently applied have been described and the technical capabilities and limitations of different forms of monitoring have been reviewed. The aim of the review was to determine which types of monitoring are the most effective to the optimise protection against internal exposures.

5. Conclusions

5.1 Review of the number of exposed workers and magnitude of internal doses in EU NORM industries

The results have revealed that there still is a severe lack of information on the number of exposed workers in NORM industries and the associated occupational doses. The studies carried out so far, on a national level in response of the implementation of Title VII of the European BSS or ordered by the European Commission, do not provide the information for a scientifically sound evaluation of the problem. The number of 85,000 exposed workers, as derived in this study, warrants more research in this area.

There are some observations to be made with respect to this assessment.

- The available data were very scarce and originating from only a few of the EU Member States. This necessarily led to a very rough estimation of the total number of exposed workers in the EU.

- The greatest group of exposed workers (70,000) seems to be welders using thoriated welding electrodes. The data that do exist suggest that grinding of welding rods may give rise to doses between 6 and 20 mSv per year. Although there are tens of thousands of such workers in this area, dose assessment data is surprisingly scarce. Furthermore, there is some evidence that alternative (non-radioactive) welding rods are increasingly being used. This means that the number of exposed workers should decrease in the future. Again, however, precise details on this trend were not available.

- The second largest group of exposed workers (10,000) are those trading or using phosphate fertilisers. Here also, the data are originating only from one country, i.e. Germany.

- The results indicate that, apart from grinding of thoriated welding rods, zircon milling may also give rise to doses between 6 and 20 mSv per year, in workplaces where protection measures are poor or non-existent. Rare earth processing may even give rise to doses above 20 mSv per year. In both industries, the number of exposed workers is small.

- Most of the industries give rise to doses below 6 mSv per year. With the exception of the industrial areas mentioned above, the number of exposed workers per type of industry is moderate to small. Given the rough and conservative dose assessments this is on the one hand reassuring. On the other hand, from a radiation protection point of view these dose levels are still significant and justify a closer and more specific evaluation, certainly when one compares this with the attention paid to decrease the collective and individual doses due to exposure to artificial radionuclides.

- The information gathered from the Accessing and Applicant Countries is even less than that from the EU Member States. In fact, the only project where some information may become available from some of those countries is TENORMHARM. It should be noted that some of these countries have important mining industries, several of which have considerable problems with NORM. There is no information included in Work Package 1 about this type of industries.

In most cases, exposure of workers to natural radionuclides can be reduced considerably when operators and authorities are aware of the problems. The findings of this project show that there still is a basic lack of data. The guidance of the European Commission to the EU Member States about the implementation of Title VII of the EURATOM BSS has not led to specific information, necessary to accurately assess the magnitude of the problems. It is recommended that the European Commission should promote and direct future research in this area.

5.2 Monitoring strategies, methods and tools

The co-operation with the industrial partners has contributed, to a large extent, to the success of the project. The companies were selected on the basis of the work that they have carried out in the past to understand the radiological consequences of the presence of natural radionuclides in the processes, products, residues and wastes. They all belong to the major industries in their sector and, in fact, they were the only sources of information on numbers of exposed workers and doses associated with certain types of jobs. All the companies have a long record of radiation protection research. They provided a wealth of information and data, which has been used in the project in order to formulate practical and useful recommendations for monitoring strategies, both for themselves, for other operators and for authorities.

The results of the project provide a scientific and practical basis for monitoring programs, both for individual workers and for the workplace. The importance for radiation protection is illustrated by the fact that it describes the way to use sampling equipment, which has intrinsically be designed for industrial hygiene instead of radiation protection purposes. This is by no means self-evident, since samplers cannot sample the true ambient aerosol required for radiation protection purposes. This has two notable effects, firstly in terms of assessing the activity concentration in air, and therefore the intake in Becquerels, and secondly in terms of assessing the effective dose. The results show that for specific situations a preferred sampling protocol should be used. It also provides correction factors, to be used to minimise the bias in the dose assessment, either because of unknown parameters or because of a non-ideal sampling procedure. Without such correction factors, significant errors can be made in the assessment of internal exposures.

In conclusion, the project has generated important information about practical radiation protection monitoring programs in NORM industries. It provides practical information how to assess the radiological consequences for the workforce in a first screening campaign, and how to get more information when the first screening warrants further research. By this approach, the most efficient use can be made of resources, without spending unnecessary time and money where this is not justified and by advising on the use of the right instrumentation for the job, in a way that produces the quality of results required to implement radiation protection controls.

The scientific basis for monitoring can also be relevant to manufacturers, for further development of sampling equipment, in order to make them more suitable for use in radiation protection in NORM industries.

With regard to the monitoring strategy, the following conclusions can be drawn from the study:

- The assessment of internal exposure of workers to industrial natural sources should be based on Personal Air Sampling (PAS), which is the preferable tool to identify specific workstations and tasks, and to assess the effectiveness of countermeasures against such sources.

- Static Air Sampling (SAS) and Real Time Dust Monitoring (RTDM) can be useful to identify specific sources of airborne dust, to identify specific workstations and tasks, and to assess the effectiveness of countermeasures against such sources. SAS and RTDM cannot replace PAS for dose assessment purposes.

- The dose coefficients for Type S and M natural radionuclides are AMAD-dependent, but usually there is no (detailed) information available on the particle size distribution of aerosols.

- The preferred sampling convention for PAS is thoracic for Type S and M aerosols and inhalable for Type F.

- The exposure assessment should take care of:

  ⇒ correction of the sampled activity to true ambient aerosol concentration with 5µm default AMAD (GSD 2.5) depending on the sampling convention;

  ⇒ correction of the possible underestimation in the assessed dose if the preferred sampling convention, in relation to lung absorption type, is not available;

  ⇒ application of a dose coefficient based on the actual or most likely lung absorption type of the aerosol.

- A large bias (positive or negative) can result when the dose coefficient is based on an assumed lung absorption type that is different from the true lung absorption type of the aerosol.

- Further guidance for users is needed on the statistical nature and analysis of monitoring results.

- The strategy for assessment of internal exposures of workers from industrial natural sources should comprise a graded (stepwise) approach.