PROCEEDINGS SERIES

NATURALLY OCCURRING RADIOACTIVE MATERIAL
(NORM V)

PROCEEDINGS OF THE FIFTH INTERNATIONAL SYMPOSIUM ON NATURALLY OCCURRING RADIOACTIVE MATERIAL

ORGANIZED BY

THE UNIVERSITY OF SEVILLE

IN COOPERATION WITH

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FOREWORD

All minerals and raw materials contain radionuclides of natural origin, of which the most important for the purposes of radiation protection are the radionuclides in the ^{238}U and ^{232}Th decay series and ^{40}K. For most human activities involving minerals and raw materials, the levels of exposure to these radionuclides are not significantly greater than normal background levels. Such exposures, while having been the subject of much research, are not of concern for radiation protection. However, certain work activities can give rise to significantly enhanced exposures that may need to be controlled by regulation. Material giving rise to these enhanced exposures has become known as naturally occurring radioactive material (NORM).

Historically, most regulatory attention has been focused on the mining and processing of uranium ore, because such activities are a direct consequence of the radioactivity in the ore and form part of the nuclear fuel cycle. Over the past decade or two, however, more and more countries have introduced measures to regulate exposures arising from a wider range of natural sources, in particular minerals and raw materials other than those associated with the extraction of uranium. Two important developments in this regard were the establishment of the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (published in 1996 as IAEA Safety Series No. 115) and the European Council Directive 96/29/Euratom of 13 May 1996, both of which contained provisions for protective measures against significantly increased exposures of workers and members of the public to natural sources.

As a direct consequence of the Euratom Directive and its possible implications for non-nuclear industries in Europe, a symposium on NORM, the first in the current series, was held in Amsterdam in 1997. The second in the series (NORM II) was held in 1998 in Krefeld, Germany, the third (NORM III) in Brussels in 2001 and the fourth (NORM IV) in Szczyrk, Poland in 2004. In addition, a symposium on Technologically Enhanced Natural Radiation was held in Rio de Janeiro in 1999, reflecting the growing interest within regions beyond Europe in the management of exposure to NORM. The close involvement of the IAEA in most of these symposiums is reflected in the fact that the proceedings of the Rio de Janeiro and Szczyrk symposiums have been published as IAEA-TECDOC-1271 and IAEA-TECDOC-1472, respectively. This involvement has been significantly expanded in the case of NORM V. The IAEA entered into a formal cooperation arrangement with the organizing body, the University of Seville, in terms of which the IAEA, in addition to publishing these Proceedings, served on the Steering Committee and Scientific Committee of the symposium and provided financial support to several participants from Member States eligible to receive assistance under the IAEA technical cooperation programme. These activities were undertaken as part of the IAEA's programme to promote the application of the safety standards, in this case with particular reference to natural sources of radiation, and to provide for the dissemination of information among Member States.

The NORM V symposium, which was attended by 200 participants from 40 countries, was held exactly one decade after the first symposium in the series and provided an important opportunity to review the many developments that had taken place over this period. It also coincided with various current initiatives to review and revise international recommendations and standards on radiation protection and safety. The Proceedings contain all 37 oral presentations and four rapporteur reports, as well as a summary that concludes with the main findings of the symposium. Text versions of 46 poster presentations are provided on a CD-ROM, which accompanies these Proceedings.

The IAEA, on behalf of the organizer, the University of Seville, gratefully acknowledges the cooperation and support of all the organizations and individuals that have contributed to the success of this symposium.

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SUMMARY

1. Background to the symposium

1.1. Objectives

Many technical and regulatory developments concerning exposure to naturally occurring radioactive material (NORM) have occurred during the ten years since the organization of the first in this series of symposiums. This symposium, the fifth in the series, provided an important opportunity to review those developments, particularly the progress made in identifying, quantifying and managing the radiological risks associated with industrial processes involving NORM. It also provided a forum for discussing the way forward towards the achievement of a much needed internationally harmonized regulatory approach. This was particularly important in the light of current initiatives to revise the following major texts dealing with radiation protection and safety:

– The 1990 Recommendations of the International Commission on Radiological Protection (ICRP), published in 1991 as ICRP Publication 60;

– The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the BSS), published in 1996 as IAEA Safety Series No. 115; and

– The European Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation.

The technical programme was well subscribed and comprised 37 oral presentations and 50 poster presentations. To help realize the objectives of the symposium, arrangements were made in the programme for each day's presentations and discussions to be reviewed and summed up by a rapporteur. On the final day, the rapporteur's report-back included a review of the entire symposium and of the extent to which the objectives of the symposium had been met.

1.2. International aspects

The first NORM symposium, held in Amsterdam in 1997, had been organized in response to concerns within the non-nuclear industry in the European Union (EU) that the implementation of the Council Directive 96/29/Euratom would place unreasonable and unwarranted legal obligations on many industrial enterprises that handled and processed material containing low levels of radionuclides of natural origin. Subsequently, as new regulations for the control of exposure to NORM became established in EU Member States and as knowledge about the levels of exposure improved, those concerns diminished to some extent, although the definition of the scope of regulation remains controversial even today. Furthermore, it became apparent that this was becoming more of a global issue because of the increasingly international profile of the mining and minerals processing industry, with large quantities of minerals being mined and beneficiated in countries remote from Europe and shipped to other countries — often over vast distances — for further processing. In line with this trend, successive NORM symposiums began to take on a more international flavour and the involvement of the IAEA became progressively greater.

Given this background, specific steps were taken during the planning of the NORM V symposium to encourage stronger participation from countries outside the European Community:

(i) The Steering Committee arranged for broad international representation on the scientific committee of the symposium and encouraged the members of that committee to actively promote participation in the symposium from within their own geographic regions.

(ii) The IAEA provided financial support to nine participants from Member States eligible to receive assistance under the IAEA technical cooperation programme.

These efforts were evidently successful, in that the symposium attracted some 200 participants from 40 countries, far outstripping — in both respects — the participation in any of the previous symposiums.

2. Harmonization of radiation protection standards and regulatory approaches

2.1. Key concerns

The keynote address delivered during the opening session of the symposium focused attention on the need for moving towards a harmonized approach to the management of exposure to NORM, especially given that minerals and raw materials are traded internationally on a very large scale and bearing in mind the opportunity provided by the current initiatives to revise international recommendations and standards. While there had been some progress towards harmonization at the international level, the question remained as to whether consensus on this matter was really being achieved. Even the definition of NORM itself was not universally agreed upon and there were different interpretations as to which exposures to NORM should be subject to the requirements for practices and which should be subject to the requirements for intervention.

Of particular concern were the numerous and significant inconsistencies between countries in the application of regulatory control measures. Instances were mentioned of countries extending the scope of regulation down to values of activity concentration that were five or ten times lower than those agreed upon in international forums. Several examples were quoted of severe disruption to international trade because of these inconsistencies, including some instances of imports of minerals being prohibited, even though their activity concentrations were sometimes well within the range for normal rocks and soil. It was also pointed out that a significant factor in all of this was the heavy reliance on modelling using hypothetical exposure scenarios to assess the exposures of workers and members of the public. Depending on the degree of conservatism adopted, these modelling assessments gave results that could differ by more than two orders of magnitude, leading to the possibility of false conclusions being drawn on the need for regulation. However, it was recognized that in the ten years that had elapsed since the first NORM symposium in this series, considerable progress had been made in improving the reliability of exposure assessments through the increasing use of facility-specific measurements. It was hoped that this positive development would now lead to a more common understanding of the radiological risks involved and thus to a more harmonized regulatory approach.

2.2. The definition of NORM

Since all materials contain radionuclides of natural origin, it was emphasized by several speakers that there is a need to distinguish between the few that require regulatory attention and the vast majority that do not. The fact that NORM is an acronym for 'naturally occurring radioactive material' had led to a tendency in some quarters for all minerals to be regarded as NORM, with the erroneous implication that they were therefore all radiologically hazardous and in need of regulatory control. One attempt to distinguish those materials that needed to be regulated had been to introduce the term TENORM, an acronym for technologically enhanced NORM, but it was pointed out on more than one occasion that this did not solve the problem and was potentially confusing because there was no direct correlation between the need for regulation and the application of any industrial process. The IAEA had addressed the issue by adopting only the term NORM in the international safety standards while restricting the definition of this term to include only material that was radioactive in the regulatory sense (i.e. material that was subject to regulation because of its radioactivity) and not to include other material that was radioactive only in the scientific sense.

2.3. Practice or intervention?

The recommendations in ICRP Publication 60 utilize the concepts of practices and interventions for the purposes of defining the approach to radiation protection and, accordingly, the BSS is based firmly on these two concepts. However, for exposure to natural sources, the distinction between the two concepts has not always been clear, particularly where there are elements of both practices and intervention at the same site. This was the situation described in a paper from Nigeria relating to the assessment of exposures from tailings generated by the mining and processing of heavy mineral deposits. The need for remedial action was identified, in order to reduce doses to the local population from residues from past, unregulated activities, while at the same time there was a need to establish appropriate levels of protection for ongoing operations, implying a need to achieve compliance with the 1 mSv dose limit for members of the public. The situation was further complicated by the fact that the local population were, on an informal basis and to an increasing extent, excavating the ore using simple tools and processing it in their backyards, raising the question of whether these individuals should be regarded as workers or members of the public for the purpose of radiation protection. It was stated in the presentation that the implementation of remedial measures (in accordance with the requirements for intervention) would be followed by full or partial implementation of radiation protection measures for practices.

A further example of the 'grey' area between practices and intervention was illustrated in a paper from the European Commission. The European Council Directive 96/29/Euratom requires that work activities involving the (unintended) presence of natural sources and leading to significantly increased exposures are subject to all or part of the requirements for both practices and interventions, as necessary. This was reported to have led to different regulatory approaches in different European Member States. As a consequence, in the revision of the Euratom Directive, consideration was being given to defining more precisely those NORM activities that should be regulated as practices, with the regulatory requirements for such activities then being essentially the same as those for practices involving exposure to radionuclides of artificial origin. A so-called 'positive list' of work activities involving NORM was being proposed, specifying those work activities that require the attention of the regulatory body. If a NORM activity was not on the list, the regulatory body would not need to be notified. This list was very similar to a list in IAEA Safety Reports Series No. 49: 'Assessing the Need for Radiation Protection Measures in Work Involving Minerals and Raw Materials', which specified the industry sectors most likely to require some form of regulatory consideration. The similarity between these lists was an example of how an improved understanding of the radiological risks from NORM had led to a convergence of views on where regulatory attention should be focused.

During the keynote address, attention was drawn to the approach adopted in the BSS whereby exposures to natural sources are generally subject to the requirements for intervention but that certain exposures are, by exception, subject to the requirements for practices. These exceptions are listed in the BSS as public exposures to discharges and radioactive waste arising from practices involving natural sources, certain occupational exposures to radon, and any other occupational exposures specified by the regulatory body. Although the last mentioned exception involves judgement by the regulatory body, attention was drawn to the guidance provided in a related IAEA Safety Guide, which states that it is usually unnecessary to regulate (as a practice) material in which the activity concentrations are below 1 Bq/g for uranium and thorium series radionuclides and 10 Bq/g for ^{40}K. It was reported that, in accordance with General Conference Resolution GC(48)/RES/10 of September 2004, these activity concentration criteria are now being proposed for inclusion in the revised version of the BSS as 'entry levels' for the application of the requirements for practices.

It was emphasized that the activity concentration criteria of 1 and 10 Bq/g are order-of-magnitude values (in line with the approach taken already for exemption values in the BSS and the Euratom Directive) and are not based on dose considerations but rather on the upper bound of activity concentrations in the natural environment, as reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The values are intended to be used either to define the scope of national regulations or to define what should be regarded as radioactive material for the purpose of such regulations. In addition, they can be used to determine whether material from within a practice can be released from regulatory control. In the presentation from the European Commission, it was reported that the same criteria were being considered for adoption into the revised Euratom Directive. In the final rapporteur presentation of the symposium, it was concluded that these criteria were becoming increasingly supported, albeit with a few reservations for specific exposure situations, and that their adoption was the most viable way forward towards a harmonized regulatory approach.

It was also pointed out that the transport of radioactive material, including NORM, is a practice that is subject to the requirements of the Regulations for the Safe Transport of Radioactive Material (IAEA Safety Standards Series No. TS-R-1), commonly referred to as the Transport Regulations. However, in the case of "natural material and ores containing naturally occurring radionuclides that are either in their natural state, or have been processed only for purposes other than for the extraction of the radionuclides, and that are not intended to be processed for use of these radionuclides", these regulations do not apply unless the radionuclide activities or activity concentrations exceed certain values specified in the regulations. For ^{238}U and ^{232}Th in equilibrium with their progeny, the applicable value of activity concentration is 10 Bq/g. However, there was a lack of clarity on what exactly was meant by the term 'natural material' and this was raised as a concern on more than one occasion. For instance, a zirconia refractory is a product, for industrial use, manufactured from zirconia raw material — was this product a natural material or not? The symposium concluded that, for the purpose of safety in transport, there was no sense in differentiating between raw materials and those same materials after they had been processed into 'objects', but the Transport Regulations could be interpreted as meaning that the latter no longer fell within the definition of 'natural material'. Consequently, a strong plea was made for the standards to be clarified accordingly.

2.4. Criteria for exemption

As mentioned in Section 2.2, for the purposes of international standards the IAEA had chosen to define NORM as material containing radionuclides of natural origin at levels that require it to be subject to regulatory control. Except for certain commodities (e.g. foodstuffs, drinking water and building materials) and residues in the environment, this regulatory control would be implemented in accordance with the requirements for practices. However, it was emphasized on several occasions that, for NORM, it was especially important to apply a graded approach to the regulation of practices, because the radiological risks vary over a wide range, depending on the type of practice, and are often very low. The first level of this graded approach was a regulatory decision that the optimum regulatory option was not to apply regulatory requirements to the legal person responsible for the material, i.e. to grant an exemption. It was encouraging to note from the presentations and discussion that there now seemed to be unanimous recognition that the so-called 10 μSv criterion for exemption (the criterion of 'trivial dose') was not appropriate for activities involving NORM and that a value of the order of 1 mSv in a year was more likely to be consistent with the optimum use of regulatory resources. Many countries mentioned, either directly or by implication, that the value of 1 mSv was indeed being used as an exemption level and in the final rapporteur presentation it was concluded that this was now commonplace as a de facto NORM standard. For example, it was reported that in Germany "Control of residues [from industrial processes with enhanced natural radioactivity] is required if the processing or disposal of these residues could result in the reference effective dose of 1 mSv in a calendar year being exceeded". The European Commission reported that exemption criteria of 1 mSv in a year for occupational exposure and 0.3 mSv in a year for public exposure were being considered for adoption into the revised Euratom Directive.

The European Commission also reported on a proposal to incorporate into the revised Euratom Directive certain criteria for radionuclides of natural origin in building materials. These criteria, which are currently published only as guidance, are expressed in terms of incremental dose from gamma radiation. Building material giving rise to a dose not exceeding 0.3 mSv per year would be exempt from all restrictions. In connection with this, the concept of an activity index based on the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K was proposed as a screening tool for identifying materials that might be of concern.

It was mentioned on more than one occasion that there were currently no universal exemption criteria expressed in terms of activity per unit surface area. This was an issue affecting decisions on the removal from regulatory control of items whose surfaces were contaminated by NORM, for instance pipes and other equipment from the oil and gas industry. One presentation highlighted the fact that not only were there differences in numerical values between countries but also differences in the choice of parameter, e.g. beta activity concentration, alpha activity concentration, a combination of beta and alpha activity concentrations, or the activity concentrations of individual radionuclides. It remains to be seen whether it would be feasible to develop universally applicable exemption/clearance levels for surface contamination with respect to NORM.

3. Industrial processes involving NORM

The scope of the symposium was intended to be focused on important NORM industry sectors (other than the mining and extraction of uranium) that had received less attention in the past or that were associated with issues of particular topical interest. Consequently, dedicated sessions were organized for the following six industry sectors:

(i) Thorium and its industrial applications;

(ii) Processing and use of zircon and zirconia;

(iii) Production of titanium dioxide pigments;

(iv) Monazite and the extraction of rare earths;

(v) Extraction, processing and use of phosphate minerals;

(vi) Scrap recycling and waste management.

Except for the session on thorium, each session started with an invited overview paper in order to set the scene. The papers were delivered by experts from India, South Africa, Spain, the United Kingdom and the United States of America. Information was presented on industrial processes, exposure levels and radiation protection measures, as follows:

- The presentations dealing with the zircon/zirconia, titanium dioxide and phosphate industry sectors provided summaries of information that is currently being incorporated into IAEA Safety Reports. In the case of zircon/zirconia and titanium dioxide, this information represents the first comprehensive review of the radiological aspects of these industry sectors.
- The phosphate industry is a much broader topic, and the radiological aspects of the main processes have been studied in some detail over many years. Consequently, the presentation on the phosphate industry focused only on the wet-acid processing route, which is the dominant production mode for phosphoric acid and its derivative fertilizers. Using inhalation dose characterization as an example, it highlighted the need for a global initiative to establish benchmark data that would lead to greater reliability in estimating radiological hazards and thus reducing the tendency for over-regulation. For instance, personal monitoring programmes persist at facilities throughout the world despite the fact that in many cases they achieve no practical benefit and the facilities would qualify for the lowest level of the graded approach, i.e. no regulation necessary.
- The presentation on monazite and the extraction of rare earths was of particular interest because this industry sector is characterized by exposure levels that are generally higher than those found elsewhere, the chemical extraction processes are rather specialized and consequently not widely understood, and significant quantities of waste with relatively high activity concentrations are generated and have to be managed accordingly.

– The presentation on scrap recycling described a voluntary protocol that had been established in Spain through cooperation between representatives from government and industry and that had now been in operation for eight years. The success of the protocol was demonstrated by the fact that, through this constructive and cooperative approach, Spain had now achieved international prominence in the control of radioactive materials (including NORM) in scrap.

In addition to these dedicated sessions, two 'miscellaneous' sessions were organized, in which other NORM industry sectors such as the production of iron and steel, the extraction of oil and gas, the processing of bauxite and the mining of copper were covered.

4. Dose assessments and their limitations

4.1. Doses received by workers

Comparisons of the results of various dose assessments for workers were highlighted in the symposium. These comparisons revealed large discrepancies due to differences in parameter values used in the calculations. Facility-specific measurements were replacing generic assumptions to an increasing extent, leading to a better appreciation of the overestimation that could result from the use of unrealistic assumptions. Such overestimation could in turn lead to false conclusions being drawn on the need for and extent of regulation. The following examples were mentioned during the keynote address:

– Processing of phosphates: doses overestimated by up to 86 times;

– Processing and use of zircon/zirconia: doses overestimated by up to 2000 times;

– Extraction of rare earths from monazite: doses overestimated by up to 1200 times;

– Production of titanium dioxide pigments: doses overestimated by up to 1500 times.

Further examples came to light during other presentations. Assessments reported from Spain and Germany, based on the assumption of a 2000 h annual exposure period, gave the following comparisons with assesments reported elsewhere based on actual exposure periods:

– External gamma doses in zircon storage facilities: 1.0–3.3 mSv/a (2000 h) compared with 0.25–0.28 mSv/a (actual);

– Dust inhalation in zircon milling operations: 0.5–2 mSv/a (2000 h) compared with 0–0.7 mSv/a (actual).

In the presentation from the United States on wet-acid phosphate processing, it was reported that earlier estimates of worker inhalation doses based on assumed dust parameter values (activity mean aerodynamic diameter, activity concentration and particle solubility in lung fluid) gave annual doses of 2.85–5.60 mSv, whereas more recent calculations based on measured values of these parameters gave doses "well below 1 mSv/a", even for phosphate rock with activity concentrations at the upper end of the range of activity concentrations found in commercially exploited material.

The results of various dose assessments reported during the course of the symposium are summarized in Table 1 and provide further confirmation of the general conclusions from previous work involving occupational exposure to NORM. For most of the industrial processes concerned, worker doses were generally too small to warrant regulatory control, especially when taking into account the effects of normal occupational health and safety (OHS) measures such as respiratory protection in dusty areas. One notable exception was the industry sector dealing with monazite and extraction of rare earths, where significant doses could be received by workers as a result of the high thorium content of monazite and the nature of the processes involved.

The production of thorium-containing gas mantles was also identified as potentially giving rise to exposures of regulatory concern, although it was pointed out that the use of thorium in most industrial applications, including gas mantles, was being phased out as substitutes became available. Thorium was still regarded as essential for the production of high intensity discharge lamps and, to some extent, of TIG welding rods, but the doses associated with these applications were too low to be of regulatory concern. In the case of TIG welding rods, some substitution for thorium was already occurring and the Swedish authorities were reported to be considering steps to encourage a more rapid change to new materials.

TABLE 1. SUMMARY OF WORKER DOSES REPORTED IN THE SYMPOSIUM

	Annual effective dose (mSv)		
	Minimum	Typical	Maximum
Production of gas mantles	~1		~10
Gas lantern maintenance		~0.2	
Storage of TIG welding rods		~0.002	
Manual TIG welding			0.15
Robotic TIG welding		Negligible	
Thorium-containing lamps		Negligible	
Recycling of thorium electrodes (TIG welding and lamps)			0.3
Bulk storage of zircon	0.25		0.28
Zircon milling		0.8[a]	
Production of zirconia by thermal processing of zircon	0.7		3.1
Production of zirconia, zirconium chemicals and zirconium metal by chemical processing of zircon	0.5		1
Manufacture of ceramics containing zircon or zirconia	0.01		1
Manufacture of refractories containing zircon or zirconia	0.05		0.8
Use of zircon in foundries			0.5
Manufacture of cathode ray tubes containing zircon			0.4
Manufacture of zirconia-containing abrasives			1
Bulk storage of ilmenite	0.03		0.08
Manufacture of titanium dioxide pigments			1[b]
Separation of heavy minerals from monazite-containing ores[c]	~1		7
Chemical extraction of rare earths from monazite	3		9
Manufacture of phosphate fertilizer, wet-acid process (dust)	0.02		0.8
Manufacture of phosphate fertilizer, wet-acid process (gamma)			0.8
Elemental phosphorus production		1	
Refurbishment of oil extraction equipment	0		0.93
Melting of thorium-containing scrap metal			0.3
Separation and fractionation of natural gas	0		0.02
Production of ethylene and polyethylene from natural gas	0		1.6

[a] Higher doses, up to 3.3 mSv, were reported but were based on an assumed annual occupany of 2000 h rather than the actual occupancy (see comments in the text).

[b] For the sulphate process, the annual dose in the hydrolysis and Moores filtration areas could be up to 6 mSv in the absence of controls.

[c] In addition, worker doses estimated using conservative assumptions to be potentially in the range 8–125 mSv/a were reported for a heavy minerals separation plant in Brazil, principally due to dust inhalation, but these estimates were made were prior to the implementation of actions that significantly reduced exposures.

4.2. Doses received by members of the public

Several presenters reported on the results of public exposure assessments. A summary of these results is given in Table 2. The assessments were generally regarded as conservative; nevertheless, the doses were in most cases found to be only a small fraction of a millisievert. The highest doses were those calculated for the future use of landfill disposal sites, either in controlled situations (authorized industrial use) or uncontrolled situations (intrusion), but even in these situations the doses were significantly below 1 mSv.

TABLE 2. SUMMARY OF PUBLIC DOSES REPORTED IN THE SYMPOSIUM

	Annual effective dose (mSv)		
	Minimum	Typical	Maximum
Zircon milling	0.00001		0.32
Production of zirconia by thermal processing of zircon		0.037	
Chemical processing of zircon		Negligible	
Stack emissions from a ceramic tile plant (per caput)			0.0001
Use of glazed tiles containing zircon	0.009		0.113
Stack emissions from a zircon refractories plant			0.0001
Zirconia in cathode ray tubes		Negligible	
Titanium dioxide pigment manufacture		Negligible	
Mining and beneficiation of phosphate rock	0.017		0.021
Thermal phosphorus production		0.001	
Use of phosphorus slag for road construction	0.001		0.06
Mining and beneficiation of copper ore and phosphate rock			0.2
Disposal of red mud from bauxite processing		0.01	
Landfill, off-site resident			
Disposal of zircon foundry sand		0.0006	
Landfill, use of land for industrial purposes			
Use of tin slag for land reclamation			0.45[a]
Landfill, intrusion following loss of control			
Disposal of used zircon foundry sand	0.002		0.13
Disposal of zircon fusion dust		0.0045	
Disposal of zircon chemical processing waste		0.75	
Disposal of zircon refractories plant waste	~0.001		~0.01

[a] Maximum dose received by workers on the reclaimed site.

As in the case of occupational exposures reported in Section 4.1, these results provide further confirmation of the general conclusions from previous work involving exposure to NORM. Furthermore, some presenters again drew attention to discrepancies in the results of dose calculations due to differences in the assumptions used in various dose calculations, as illustrated by the following examples:

– A presentation from South Africa reported on the results of a public dose assessment conducted for a large mining and minerals processing complex. Dose contributions from inhalation (dust, radon and thoron) and ingestion (foodstuffs and drinking water) were calculated for groups of individuals at nine locations in the vicinity of the complex. The results of an initial, conservative assessment indicated that the annual doses received by individuals in these groups varied from 0.058 to 0.254 mSv.

Although these doses were already rather low, the assessment was repeated using more realistic assumptions regarding airborne dust levels, amounts of local food consumed, the agricultural use of the land and the extent of groundwater utilization. For three of the nine groups, the doses remained the same, but for the remaining six groups the doses were found to be substantially reduced — in some cases more than 90% lower.

– During the keynote address, attention was drawn to an issue of public exposure in connection with the 1 Bq/g activity concentration criterion for uranium and thorium series radionuclides in materials, below which it was generally considered unnecessary to regulate (see Section 2.3). Although this criterion had not been derived using a dosimetric approach, it had nevertheless been accepted at the time of adoption that it was generally consistent with a maximum dose of about 1 mSv except, possibly, where the material was used for construction of dwellings. This was now being questioned in the light of modelling results reported from Germany, which predicted that an adult residing next to a mine residue deposit with an activity concentration of 1 Bq/g could receive an annual dose via the drinking water pathway of nearly 6 mSv while for a child of 1–2 years the dose would be more than 10 mSv. However, a similar modelling exercise based on more realistic assumptions supported by measured data predicted annual doses of only 0.05–0.1 mSv for both adults and children. This large discrepancy underlines the need for caution when using modelling predictions as the basis for determining the need for regulation.

5. Discharges to the environment

Several presentations reported on liquid and aqueous discharges from mining and mineral processing operations, including data from various environmental measurements made in the vicinity of specific industrial facilities. In every case, the radiological impact was reported as being insignificant or zero. It was clear from the presentations that environmental regulations played a major role in ensuring that pollutants, including radionuclides, were to a large extent removed before discharge. The increased recycling of water and/or the use of various effluent treatment techniques such as neutralization, settling and precipitation were mentioned in connection with a wide range of industrial facilities, including the mining of copper, the chemical processing of zircon, the production of titanium dioxide pigments, the extraction of rare earths from monazite and the production of iron and steel. In many cases, the radionuclide content of the discharged water was similar to local environmental levels. At a mineral sands processing plant in Brazil, it was reported that the radionuclide concentrations in the liquid effluent from the hydrogravimetric concentration process were actually lower than those found upstream of the discharge point.

The overview paper on monazite and the extraction of rare earths provided information from India on the discharges associated with the chemical extraction process. This information was of particular interest because the radionuclide activity concentrations in various of the process materials are unusually high throughout the extraction process and the quantities of liquid effluent produced are large (15 m^3 per tonne of monazite processed). It was reported that, before treatment, the acidic and alkaline effluent streams contain ^{228}Ra at concentrations of several hundreds of becquerels per litre. Following the treatment and mixing of these streams, the radionuclides are co-precipitated with calcium phosphate. Discharge of the supernatant liquid to a river is then carried out in compliance with authorized discharge limits. As a result of improved effluent management at one plant over the past 20 years, the activity in the water and sediment had shown a reduction of 3–4 times and the dose received by a member of the public via the fish consumption pathway was negligible. It was also reported that gaseous and airborne particulate emissions from the plant were well below the applicable discharge limits and the environmental impact of these emissions was insignificant.

Treated water discharged from a copper mining operation in Zambia was reported to have very low radium activity concentrations (from <0.03 to about 0.04 Bq/L). The radium concentrations in the suspended solids were also very low at about 0.06–0.08 Bq/g. In view of these results, it was interesting to learn that unacceptable pollution was nevertheless considered to be taking place because the Zambian legal limit for discharge of radioactivity to the environment was zero.

Protection of the environment was the subject of a paper from Norway, which described a project being undertaken to establish safe limits for the discharge of formation water from oil and gas facilities in the North Sea. This water contains enhanced concentrations of ^{226}Ra, ^{228}Ra and other radionuclides of natural origin. The discharge limits are to be established on the basis of doses received by marine biota as well as humans. Reference organisms have been chosen for this geographic area for the purpose of modelling activity concentrations in seawater and biota and calculating doses. A conceptual model of radiological responses of organisms, populations and ecosystems has been proposed. It was suggested that the discharge limit should be based on an absorbed dose to biota of 5 mGy/h.

6. Use, reuse and recycling of NORM residues and NORM-contaminated items

6.1. Regulatory approach

Several presentations referred to options for use, reuse and recycling as a means for reducing the quantities of material that need to be disposed of as NORM waste. In Europe in particular, this was starting to be reflected in standards and regulations. It was reported from the European Commission that a proposal had been made to incorporate into the revised Euratom Directive specific provisions for the reuse and recycling of residues, including provision for authorizing their dilution with non-radioactive material where this was identified as the optimum option. It was reported from the Netherlands that the option of recycling or recovery is explicitly mentioned in Dutch regulations and that the general approach was to give priority to identifying by-products that could be safely developed out of NORM residues using the principle of dilution with non-radioactive material where necessary.

In a presentation on the international project ‘Stack Fee by 53? Beneficial Uses of Phosphogypsum’, it was pointed out that, since 1992, the United States Environmental Protection Agency (EPA), concerned about potential risks from the radioactivity in phosphogypsum, has defined this material as a toxic waste, with containment in stacks as the only acceptable management and disposal method for most of the material, despite the fact that large quantities of phosphogypsum can be safely put to beneficial use. This decision by the EPA was reported to have had a strong impact on the rest of the world’s perceptions of phosphogypsum and its regulatory regimen. One case in point highlighted in the presentation was the suspension of the traditional practice in Spain of spreading phosphogypsum on local soils both for reclamation and as a fertilizer, as a result of an injunction sought by local environmental groups. The case was based partly on invocation of EPA standards. It was reported that the local farmers challenged the injunction and were granted relief, enabling the practice to resume on condition that close monitoring of potential environmental impacts and plant take-up was maintained. The monitoring results have demonstrated that the use of phosphogypsum in this way is safe and beneficial, with the result that it is now registered under Spanish law as a fertilizer. A further benefit is that a former phosphogypsum stack has now been reclaimed for a public park in a densely populated area..

6.2. Uses of phosphogypsum as a co-product of phosphate fertilizer production

It was reported that one outcome of the work undertaken so far in connection with the ‘Stack Free’ project mentioned in Section 6.1 was that more than 50 beneficial uses of phosphogypsum had been identified, of which the top four with respect to potential volumes of use are agriculture, construction materials, landfill management and roads. The scale of potential use could result in a significant reduction of new phosphogypsum tonnage and even, in suitable settings, the removal of stacks altogether. Symposium participants were informed that the activities under this project and the activities of the IAEA in developing and implementing international safety standards are now being coordinated and combined, with one important aim being to generate the following sequence of tiered publications designed to negotiate the basis for a transparent, safe practice of phosphogypsum use:

– An IAEA Safety Report on Radiation Protection and NORM Residue Management in the Phosphate Industry;

– A 'White Paper' on Good Phosphogypsum Management Practices;

– A set of manuals, with associated management aids and decision support tools, that will address to a level of operational detail topics such as phosphogypsum in road beds and, where possible, will be coupled with training and support systems that effect and support knowledge transfer.

A presentation by the University of Seville described work carried out to assess the agricultural use of phosphogypsum as a calcium amendment in reclaimed salt-marsh soils in south-western Spain. The work investigated the concentrations of radionuclides and heavy metals in phosphogypsum, their effect on soils and drainage waters and their transfer from soil to plants. The results showed that, although some of the environmental impacts of radionuclides and heavy metals in the phosphogypsum were measurable:

– Radon exhalation rates remained within the range of reference values for typical agricultural soils;

– Concentrations of radionuclides and heavy metals in the soil remained within the range of typical environmental values;

– Radionuclide concentrations in drainage waters remained close to the standards for drinking water;

– The contamination of foodstuffs by radionuclides and heavy metals was inconsequential.

It was concluded that the beneficial use of phosphogypsum as a soil amendment, which has been practised for the last 30 years in the area concerned, could continue safely for several decades in compliance with current safety regulations.

6.3. Uses of NORM residues as filling materials for construction

In a presentation from Sweden, it was reported that blast furnace slag from the steel industry, with a ^{226}Ra concentration of 0.25 Bq/g, is used as a filling material for construction of roads and buildings, although in the case of the latter, preventive measures are recommended to ensure that indoor radon concentrations do not exceed 200 Bq/m^3. In addition, burnt alum shale, found in former alum shale mining areas in Sweden, has been extensively used as a filling material for construction of tennis courts and sports grounds, while its use as filling material for housing construction had proved unsuitable due to high indoor radon concentrations. In Malaysia, the use of 85 000 t of tin slag with a ^{226}Ra concentration of more than 4 Bq/g was reported to have been approved for reclaiming a swampy area for light industrial use, on the basis of a dose assessment that predicted, conservatively, a maximum annual effective dose of 0.45 mSv to a worker on the site.

6.4. Use of red mud as a building material component

It was reported from Germany that efforts to identify industrial uses for red mud — a bulk residue from bauxite processing — had not produced any positive results. However, in a paper from Hungary it was reported that, from the point of view of gamma radiation, red mud would be considered acceptable for use as a component of building material, for instance bricks, if used as an additive (maximum 20 wt%) to other materials. In most manufacturing processes, these materials would include, in addition to clay, components such as sawdust and polypropylene pellets to improve the porosity, strength and thermal insulation. It was shown that by increasing the firing temperature to above 800°C and optimizing the use of additional materials, for instance adding sawdust at 15–25 wt%, the radon emanation coefficient could be reduced by up to 80%.

6.5. Recycling and reuse of NORM-contaminated materials and equipment

Several presentations referred to the recycling of equipment from the oil and gas industry, where metal items such as pipes, vessels, pumps and valves become contaminated with scale containing radium, sometimes at high concentrations. Two basic recycling options were mentioned:

(i) Melting of the contaminated items at a dedicated recycling facility;

(ii) Decontamination of the items by washing and/or mechanical techniques to render them suitable for reuse or for recycling in a conventional melting facility.

The first option was addressed in a paper from Germany, which described the radiological conditions in a dedicated melting facility for contaminated metal scrap. It was pointed out that the nature of the contamination of oil and gas industry equipment could be both radioactive (up to about 1000 Bq/g ^{226}Ra) and chemical (mostly mercury) and that only about 50% of the scrap was radioactively contaminated. The German facility was also used for melting scrapped welding electrodes and lighting elements containing ^{232}Th at activity concentrations of 12–15 Bq/g. As reported in Table 1, annual effective doses received by workers in the facility did not exceed 0.3 mSv.

With regard to the second option, decontamination of oil industry equipment contaminated with scale with ^{226}Ra and ^{228}Ra activity concentrations of up to 1670 Bq/g was addressed in a paper from Argentina. As reported in Table 1, annual effective doses received by workers at the facilities concerned were estimated to be less than 1 mSv.

The invited paper from India on mineral sands separation and chemical extraction of rare earths made reference to contaminated materials and equipment arising from decommissioning of extraction facilities. As mentioned in Section 3, the relatively high concentrations of thorium decay series radionuclides in the monazite feedstock leads to similarly high concentrations in other materials throughout the process, implying that the recycling and reuse of materials and equipment needs to be approached with care. It was reported that large surface contaminated items such as tanks were decontaminated so that they could be recycled in conventional melting facilities. Filters, electrical fittings and pipes were also decontaminated (by washing) and then recycled in conventional melting facilities or reused. Contaminated structural material and floor and wall cement plaster chippings were not recycled, however — they were instead disposed of as NORM waste either in earthen trenches or engineered cells, depending on the degree of contamination.

The invited paper from Spain on scrap metal recycling (see Section 3) highlighted some important realities with regard to the control of radioactive contamination in the recycling of scrap metal at conventional melting facilities. Because of the serious consequences of radioactive sources such as ^{137}Cs being inadvertently melted, a high degree of public and political sensitivity had been generated on the issue of radioactivity in scrap. This sensitivity could be expected to apply equally to radioactivity introduced through NORM contamination. Since the implementation of a control protocol in Spain, it had been found that 43% of all radioactivity detections at the entrances to scrap recycling facilities were due to NORM. In what would appear to be a practicable and effective approach to the implementation of the protocol, the action taken in response to a detection was determined in the first instance on the basis of dose rate measurements, irrespective of whether the radionuclide concerned was of artificial or natural origin. For NORM, this should ensure that highly active contaminants such as pipe scales are identified and dealt with appropriately.

7. Conditioning, storage and disposal of NORM waste

7.1. Bulk mining and mineral processing waste

Several references were made to the large quantities of low activity tailings produced in various types of mining and beneficiation operations and the need for their containment. A presentation from South Africa referred to the radiological impacts on the public of mine residue deposits from a copper and phosphate mining and beneficiation complex (see Section 4.2). Another presentation referred to tailings from mineral sands separation in India, most of which have activity concentrations below 1 Bq/g and are returned to the dredged area and used as backfill.

Even for countries with little or no mining activity, examples were given of the need to dispose of large quantities of low activity residues from mineral processing operations. It was reported from the Netherlands that bulk mineral residues containing low concentrations of radionuclides of natural origin are disposed of in existing hazardous waste repositories (surface containments) with only minor additional measures being needed to take care of the radiological aspects. Several papers referred to the disposal of bulk quantities of red mud (e.g. 900 000 t/a in Germany). The residue was described as chemically stable and non-toxic, with radionuclide activity concentrations well below 1 Bq/g. It was reported from Germany that red mud is disposed of in special fenced off areas in accordance with national disposal regulations. Investigations at a large disposal site revealed negligible impact on surface water and groundwater. Internal exposure of members of the public via dust inhalation was also found to be trivial. A modelling exercise based on the results of leachability measurements was applied to a red mud disposal site in Eastern Europe. It was concluded that the migration of radionuclides is restricted to the immediate vicinity of the disposal site and that there is little or no impact on groundwater or agricultural products. Similar results were obtained for bulk residues from coal mining and coal-fired power generation facilities in the same region. The hazard from heavy metals and organic compounds was stated to be greater than that from radioactivity.

Although the radiological impact of these bulk wastes has repeatedly been shown to be very low when they are suitably contained, it was pointed out in a presentation on phosphogypsum residues that the huge volumes of phosphogypsum already contained in stacks (and still being generated) could have very significant cost implications at the time of final closure, particularly for older designs of containment. Aside from the aspects of financial liability, it was also pointed out that there is growing concern that even in terms of safety and environmental legacy, the stacking of phosphogypsum may not be the best long term solution when, as an alternative, phosphogypsum can be put to various uses as a by-product.

7.2. Waste designated for disposal in landfill facilities

Several references were made during the course of the symposium to the use of landfill facilities for the disposal of NORM waste containing moderately elevated levels of uranium and thorium series radionuclides. Examples quoted in connection with the processing and use of zircon and zirconia include the following:

– Waste zircon sand;
– Precipitates from liquid effluent treatment in the chemical processing of zircon;
– Waste refractory materials containing zircon or zirconia;
– Used investment casting shells, cathode ray tubes, oxygen sensors, abrasive products.

Examples quoted from the titanium dioxide pigment industry include neutralized metal chloride impurities from the chloride process and digester residue from the ilmenite-based sulphate process.

Generally, the landfill sites concerned were facilities for conventional (i.e. non-radioactive) industrial waste and subject to normal waste disposal controls. It was noted that, in some cases, the presence of other harmful contaminants in the waste (for example, heavy metals in some used refractory linings) require the site to be specially designated for hazardous waste.

7.3. Scales and sludges

It was reported that scales and sludges from certain mineral processing operations exhibit radium activity concentrations of up to several thousand becquerels per gram. The management of these wastes in the Netherlands was described. Filter bags containing the scales and sludges are sent to a dedicated waste storage facility where they are compacted by shredding and immobilized with cement before being stored in 100 L drums. At that same facility, sludges from the oil and gas industry containing mercury and organic compounds are subjected to a specialized drying operation to evaporate the water and separate mercury, following which the material undergoes further treatment before being packaged for storage in drums. Scales and sludges arising from processes other than oil and gas extraction were mentioned during the course of the symposium. These included:

- Scale from the chemical processing of zircon (^{226}Ra up to 5000 Bq/g);
- Radium rich sludges from the production of zirconium metal;
- Scale from the sulphate process for titanium dioxide pigment production;
- Scale rich in ^{228}Ra from the chemical extraction of rare earths from monazite;
- Pipe scale from paper manufacturing facilities;
- Used filters from the treatment of drinking water.

It was evident that, in many countries, suitable regulations and disposal facilities for these types of waste had not yet been established.

7.4. Solid wastes from rare earths extraction

Monazite, a major source of rare earths, contains characteristically high concentrations of thorium series radionuclides. The solid wastes arising from the chemical processing of monazite contain correspondingly high concentrations of these radionuclides and their disposal has to be controlled accordingly. In the presentation from India on monazite and rare earths extraction, the following information on solid wastes was provided:

(a) Approximately 80–100 kg of insoluble unreacted monazite is produced per tonne of monazite processed. The ^{228}Ra activity concentration is 400–1000 Bq/g. The waste, in the form of a sludge, is neutralized and filtered and the filter cake is disposed of at engineered storage facilities consisting of trenches covered with a concrete slab and meeting specific shielding requirements.

(b) Approximately 60–100 kg of mixed cake of PbS and Ba(Ra)SO_4 is produced per tonne of monazite processed. The ^{228}Ra activity concentration is about 2000–5000 Bq/g (dry). The cake is filtered and disposed of at engineered facilities similar to those described in (a).

(c) About 100 kg of phosphate sludge from the neutralization and calcium phosphate precipitation of acidic and alkaline effluents is produced per tonne of monazite processed. The ^{228}Ra activity concentration is 25–100 Bq/g. This waste is disposed of in earthen trenches with a soil topping of 0.5–1 m. The disposal site is demarcated, fenced and identified with caution signs.

(d) Nearly 250 kg of thorium hydroxide cake is produced per tonne of monazite processed. This material gives rise to gamma dose rates similar to those in (a). It is disposed of at engineered facilities in the form of silos meeting specific shielding requirements.

7.5. Furnace dust

This type of waste was mentioned in several presentations. It originates from certain mineral processing operations involving high temperatures — high enough to cause the volatilization of ^{210}Pb and ^{210}Po. These radionuclides become selectively concentrated in the furnace dust, which is emitted to the atmosphere and/or precipitated and removed as waste. Precipitator dust from a thermal phosphorus facility in the Netherlands was described as a stable solid material that, while not requiring any conditioning or treatment, has to be stored in polyethylene lined containers at a dedicated waste storage facility in view of the particularly high concentrations of ^{210}Pb and ^{210}Po. After 150 years, it will have decayed to below clearance levels, allowing it to be disposed of as conventional waste. In other presentations, mention was made of furnace dust from facilities for the manufacture of ceramic tiles and refractories and for the production of iron and steel. These furnace dusts contain lesser concentrations of ^{210}Pb and ^{210}Po such that decay storage is not necessary and immediate disposal in landfill facilities is possible. In the case of furnace dust from a steelworks, mention was made of further studies to confirm its leaching behaviour at the disposal site.

8. Main findings of the symposium

8.1. Regulatory aspects

– Considerable progress has been made in the last ten years towards the harmonization of standards and regulatory approaches. However, the issue of harmonization remains a prospect rather than a reality and continues to be the subject of much debate. In the meantime, severe disruptions in international trade are being experienced to an increasing extent. A determined effort is therefore needed at the national and international level to achieve a common and coherent approach to the regulation of NORM.
– The activity concentration criteria of 1 Bq/g for uranium and thorium series radionuclides and 10 Bq/g for ^{40}K are, despite some reservations, generally accepted as the most practicable way forward in determining which materials should be considered for regulation in terms of the requirements for practices.
– More clarity is needed in the IAEA Transport Regulations regarding the definition of 'natural material' so that the criteria for defining the scope of the Transport Regulations can be understood as being applicable regardless of whether or not the material has been subject to processing.
– A dose criterion of the order of 1 mSv per year is now commonplace as a de facto standard for exemption of NORM from the regulatory requirements for practices.

8.2. The expanding knowledge base on exposures to NORM

– Some industrial applications of thorium have been shown to give rise to significant worker exposures, but these applications are now disappearing as non-radioactive substitutes become available. This appears to leave work involving monazite and rare earths extraction as being the only major area outside of the uranium industry where worker doses are likely to reach a substantial fraction of the dose limit. In other industrial activities involving NORM, there is growing evidence that the enforcement of normal occupational health and safety measures would most likely be sufficient to ensure that annual effective doses received by workers do not significantly exceed 1 mSv and therefore do not require the implementation of specific radiation protection measures.

- The information now available on public exposure to NORM suggests that the annual effective doses received by members of the public are likely to be always below 1 mSv provided that present-day environmental protection measures (such as the treatment of effluent streams) are applied. Indeed, the only evidence of doses even approaching 1 mSv relates to exposures arising from the occupancy of former landfill sites containing NORM.
- With the increasing use of facility-specific data for worker and public dose assessments, it is becoming ever more clear that the use of unrealistic assumptions to characterize exposure situations can give rise to very large overestimates of dose. These overestimates can in turn lead to false conclusions being drawn on the need for, or extent of, regulation. More attention therefore needs to be focused on the use of site-specific measurements for dose assessment.

8.3. Options for minimizing NORM waste

- The use, reuse and recycling of NORM residues and NORM-contaminated items — including, where appropriate, the dilution of NORM residues to reduce the activity concentration — is now starting to be recognized as a legitimate and desirable option for minimizing the quantities of NORM that need to be disposed of as waste. In particular, the beneficial (and safe) uses of phosphogypsum as a co-product of fertilizer production are now very much in the spotlight and, in some countries at least, there is already evidence of a shift in regulatory attitude towards this approach. However, when considering the use of NORM residues in the construction of dwellings, as a component of either landfilling material or construction material, the possibility of increased radon exposure needs to be carefully taken into account.
- It has been demonstrated that NORM-contaminated metal scrap can be safely recycled in a suitably controlled melting facility and this recycling option now seems to be gaining greater acceptance by the general steel industry.
- A protocol developed in Spain for controlling the inadvertent introduction of radioactively contaminated scrap into conventional scrap processing facilities, based on voluntary cooperation between all the concerned parties, is now gaining acceptance at the international level as a model for dealing with this problem. The protocol, while originally having been designed to prevent the inadvertent melting of radiation sources, is equally effective in dealing with scrap with unacceptable levels of NORM contamination.

8.4. Management of NORM residues designated as waste

- Despite the many opportunities for use, reuse and recycling, there are still many NORM residues that will ultimately have to be disposed of as waste. There is now a considerable body of knowledge on appropriate methods for conditioning, storage and disposal of the various types of NORM waste, but the necessary facilities and regulatory provisions are in many cases not yet in place.
- There is growing evidence to suggest that bulk wastes contained in properly engineered surface impoundments have very low radiological impacts. However, their environmental, safety and financial liability implications can be seriously underestimated. This has been demonstrated in the case of phosphogypsum stacks, where recent developments have suggested that the stacking option is not optimal and that more attention should be given to beneficial uses of the material.
- Landfill disposal has been demonstrated as being an appropriate option for dealing with many types of NORM residue for which the quantities and activity concentrations are moderate, including most types of furnace dust with enhanced concentrations of ^{210}Pb and ^{210}Po. Normal landfill facilities are generally suitable, but the presence of non-radiological contaminants such as heavy metals may require the use of landfill sites specially designated for hazardous waste.

- Scales and sludges, which are generated in small volumes but which may have activity concentrations reaching very high levels, such as those originating from the oil and gas industry, usually have to be held in storage pending the establishment of suitable disposal facilities. Suitable techniques exist for conditioning (e.g. separation of mercury) and long term storage.
- NORM residues from the chemical extraction of rare earths from monazite are produced in significant quantities and have characteristically high activity concentrations. It has been demonstrated that such wastes can be suitably disposed of either in earthen trenches or in engineered cells, depending on the activity concentration.