IAEA SAFETY STANDARDS SERIES

Occupational Radiation Protection in the Mining and Processing of Raw Materials

JOINTLY SPONSORED BY
IAEA AND ILO

IAEA

SAFETY GUIDE

No. RS-G-1.6

IAEA
International Atomic Energy Agency

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish standards of safety for protection against ionizing radiation and to provide for the application of these standards to peaceful nuclear activities.

The regulatory related publications by means of which the IAEA establishes safety standards and measures are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (that is, of relevance in two or more of the four areas), and the categories within it are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides.**

Safety Fundamentals (blue lettering) present basic objectives, concepts and principles of safety and protection in the development and application of nuclear energy for peaceful purposes.

Safety Requirements (red lettering) establish the requirements that must be met to ensure safety. These requirements, which are expressed as 'shall' statements, are governed by the objectives and principles presented in the Safety Fundamentals.

Safety Guides (green lettering) recommend actions, conditions or procedures for meeting safety requirements. Recommendations in Safety Guides are expressed as 'should' statements, with the implication that it is necessary to take the measures recommended or equivalent alternative measures to comply with the requirements.

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA.

Information on the IAEA's safety standards programme (including editions in languages other than English) is available at the IAEA Internet site

www-ns.iaea.org/standards/

or on request to the Safety Co-ordination Section, IAEA, P.O. Box 100, A-1400 Vienna, Austria.

OTHER SAFETY RELATED PUBLICATIONS

Under the terms of Articles III and VIII.C of its Statute, the IAEA makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety and protection in nuclear activities are issued in other series, in particular the **IAEA Safety Reports Series**, as informational publications. Safety Reports may describe good practices and give practical examples and detailed methods that can be used to meet safety requirements. They do not establish requirements or make recommendations.

Other IAEA series that include safety related publications are the **Technical Reports Series,** the **Radiological Assessment Reports Series,** the **INSAG Series, the TECDOC Series**, the **Provisional Safety Standards Series**, the **Training Course Series,** the **IAEA Services Series** and the **Computer Manual Series**, and **Practical Radiation Safety Manuals** and **Practical Radiation Technical Manuals**. The IAEA also issues reports on radiological accidents and other special publications.

OCCUPATIONAL RADIATION PROTECTION IN THE MINING AND PROCESSING OF RAW MATERIALS

SAFETY STANDARDS SERIES No. RS-G-1.6

OCCUPATIONAL RADIATION PROTECTION IN THE MINING AND PROCESSING OF RAW MATERIALS

SAFETY GUIDE

JOINTLY SPONSORED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
AND THE
INTERNATIONAL LABOUR OFFICE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2004

IAEA Library Cataloguing in Publication Data

Occupational radiation protection in the mining and processing of raw materials : safety guide / jointly sponsored by the International Atomic Energy Agency and the International Labour Office. — Vienna : International Atomic Energy Agency, 2004.

p. ; 24 cm. — (Safety standards series, ISSN 1020-525X ; no. RS-G-1.6)

STI/PUB/1183

ISBN 92-0-115003-2

Includes bibliographical references.

1. Radiation — Safety measures — Standards. 2. Mineral industries. 3. Industrial safety. 4. Raw materials. I. International Atomic Energy Agency. II. International Labour Office. III. Series.

IAEAL 03-00354

© IAEA, 2004

Permission to reproduce or translate the information contained in this publication may be obtained by writing to the International Atomic Energy Agency, Wagramer Strasse 5, P.O. Box 100, A-1400 Vienna, Austria.

Printed by the IAEA in Austria

April 2004

STI/PUB/1183

FOREWORD

by Mohamed ElBaradei
Director General

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of nuclear energy.

The following bodies oversee the development of safety standards: the Commission on Safety Standards (CSS); the Nuclear Safety Standards Committee (NUSSC); the Radiation Safety Standards Committee (RASSC); the Transport Safety Standards Committee (TRANSSC); and the Waste Safety Standards Committee (WASSC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

The English version of the text is the authoritative version.

PREFACE

This Safety Guide, which provides recommendations and guidance on meeting the requirements for the establishment of occupational radiation protection programmes in the industry for the mining and processing of raw materials, is a joint publication of the IAEA and the International Labour Office (ILO). It updates and expands on the contents of the joint IAEA–ILO–WHO Code of Practice and Technical Addendum on Radiation Protection of Workers in the Mining and Milling of Radioactive Ores, issued by the IAEA in 1983 as Safety Series No. 26. That publication was the revised version of the Code of Practice that had originally been prepared by the ILO and the IAEA jointly and was issued by the ILO in 1968 as Part VI of its Industrial Manual on Radiation Protection.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. The mining and processing of uranium ore, thorium ore and other raw materials[1] containing natural radionuclides are carried out in a number of Member States. There is a clear need to update the guidance on the radiation protection of the workers involved, and this Safety Guide provides such updated guidance. Material from two previous publications has been adapted for inclusion in this Safety Guide. These previous publications — Radiation Monitoring in the Mining and Milling of Radioactive Ores (Safety Series No. 95) and Radiation Protection of Workers in the Mining and Milling of Radioactive Ores (Safety Series No. 26, hereby superseded) — dealt principally with activities involving uranium ore and thorium ore. Activity concentrations of naturally occurring radionuclides are elevated in other mineral deposits such as heavy mineral sands and phosphate rock. Furthermore, high radon levels may be found in mines, irrespective of the activity concentrations of natural radionuclides in the raw material being extracted. In recognition of these circumstances, this Safety Guide is intended to apply also to the mining and processing of any raw material for which radiation protection measures need to be considered.

1.2. The IAEA Safety Fundamentals publication on Radiation Protection and the Safety of Radiation Sources [1] presents the principles, concepts and objectives of protection and safety. Safety requirements based on the objectives and principles specified in these Safety Fundamentals, including requirements for the protection of workers exposed to ionizing radiation, are established in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the Basic Safety Standards or BSS) [2]. These requirements also reflect the recommendations of the International Commission on Radiological Protection (ICRP) [3–6].

1.3. Safety Guides provide recommendations on the basis of international experience on the fulfilment of the requirements in several major areas. Three interrelated Safety Guides [7–9] deal with occupational radiation protection.

[1] The term ‘raw material’ is used in this publication to refer to natural materials excavated from the ground. This does not include ground that has been contaminated by radioactive material as a result of prior human activities.

The first provides guidance on meeting the requirements for occupational radiation protection established in the BSS; the other two deal with the monitoring of occupational exposure to external sources of radiation and to intakes of radionuclides, respectively, and the assessment of doses. The present Safety Guide provides recommendations and guidance on meeting the requirements for the establishment of occupational radiation protection programmes in the mining and processing of raw materials, and is based on Refs [7–9].

1.4. The 1983 edition of Radiation Protection of Workers in the Mining and Milling of Radioactive Ores (Safety Series No. 26) covered only administrative and practical aspects of radiation protection, and principally concerned uranium and thorium mines and processing facilities. The present Safety Guide includes provisions for the authorization of mining and processing activities, for inspection and compliance, and for necessary measures in the event of non-compliance with the conditions of authorization. In addition, more guidance is given for mines and processing facilities other than those exploiting uranium or thorium.

OBJECTIVE

1.5. The main purpose of this Safety Guide is to provide practical guidance for regulatory bodies on meeting the requirements for the radiation protection of workers involved in the mining and processing of raw materials. This Safety Guide will also be useful to employers, to licensees and registrants, to management bodies and their specialist advisers, and to health and safety committees concerned with occupational radiation protection. Workers and their representatives may also use it in support of safe working practices. The Safety Guide is intended to facilitate the preparation and adoption of national and local regulations and rules and working procedures for radiation protection in the mining and processing of raw materials.

1.6. As with the BSS, the guidance in this Safety Guide should be interpreted so as to take account of the scale and complexity of installations (in this case mining and processing facilities) and other factors such as the activity of the ore body and the particular minerals extracted. The coverage of the radiation protection programme should be commensurate with the nature and extent of the radiation hazards.

SCOPE

1.7. This Safety Guide covers the regulatory, technical, organizational and engineering aspects of the control of occupational exposures in facilities for the mining and processing of raw materials for situations of both normal and potential exposure. The intention is to provide an integrated approach to the control of exposures due to external and internal irradiation from both artificial and natural sources of radiation encountered in such facilities. A more comprehensive account of general occupational radiation protection is provided in other IAEA Safety Guides [7–9].

1.8. The provisions of this Safety Guide apply in the first instance to the mining and processing of uranium ore and thorium ore, and to underground exploration for uranium and thorium and activities for mine development[2]. The provisions of this Safety Guide also apply, as appropriate, to other operations in the mining and processing of minerals and raw materials for which occupational exposures to external radiation, progeny of radon or thoron, or dust may have to be controlled.

1.9. The provisions of this Safety Guide apply specifically to the occupational radiation hazards arising from operations such as: exploration, excavation and removal of ore; siting, construction and operation of a mine or a facility for physical and chemical processing of ore; and decommissioning or closure of a mine or processing facility. They may also be applied to secondary processing facilities where the concentrations of uranium and thorium and their progeny in the ore, products or residues are considered likely to give rise to occupational exposures that are required to be controlled.

1.10. Exposure of the public is outside the scope of this Safety Guide. Recommendations and guidance on the management of waste from the mining and milling of ores are provided in another IAEA Safety Guide [10].

---

[2] The term ‘development’ is used in this Safety Guide to refer to any underground or surface work carried out for the purpose of reaching and opening up a mineral deposit. This includes sinking shafts, tunnelling, and raising, and preparatory work for open pit mining.

STRUCTURE

1.11. Section 2 of the Safety Guide gives guidance on the types of mining and processing activities to which its recommendations apply and on the fulfilment of requirements for the authorization of work activities and the discharge of responsibilities for employers and workers. Section 3 covers fulfilment of the requirements for radiation protection and in particular the dose limits for practical application for mines and for the processing of raw materials, including methods for verifying compliance with the limits. Section 4 deals with programmes of radiation protection for mines and facilities for processing raw materials, with particular emphasis on the provision of specialist services in areas such as ventilation, and on monitoring for the purposes of operational control and dose assessment. Section 5 provides guidance on engineering measures for protection, including ventilation, dust control, the design and operation of processing plants, and personal protective equipment, as well as on administrative protective measures, including personal hygiene, first aid, cleanup of spills and job rotation. Section 6 covers the health surveillance of workers on the basis of general principles of occupational health.

2. FULFILMENT OF REQUIREMENTS AND DISCHARGE OF RESPONSIBILITIES

APPLICABILITY OF REQUIREMENTS AND RECOMMENDATIONS

2.1. This Safety Guide applies to all operations in the mining and processing of raw materials for which measures for occupational radiation protection and safety are required to be taken. The range of mining and processing activities falling within its scope is determined by the requirements of the BSS with respect to occupational exposure to naturally occurring radionuclides [2]. In particular, the BSS requirements are interpreted in the Safety Guide on Occupational Radiation Protection (Ref. [7], paras 2.1–2.30), and this Section is consistent with that interpretation.

2.2. For the purposes of this Safety Guide, operations in the mining and processing of raw materials are divided into four categories that cover operations involving:

(1) Uranium ore and thorium ore (i.e. ores that are mined for their uranium or thorium content) (Ref. [7], para. 2.18).
(2) Other raw materials containing elevated levels of natural radionuclides (e.g. mineral sands and phosphatic materials) or materials in which the activity concentrations of natural radionuclides have been increased by processing (e.g. deposits or scales sometimes generated in the processing of ores), for which measures for occupational radiation protection are required to protect against exposures to external gamma radiation, dust and/or radon.
(3) Raw materials that do not contain elevated levels of natural radionuclides but for which measures for occupational radiation protection are required to protect against exposures to radon arising adventitiously in the workplace environment; such operations include underground mines where radon levels are high.
(4) Other raw materials.

2.3. The stringency of control required for radiation protection for operations in mining and processing decreases from the first to the last of these categories:

- Operations involving the mining and processing of uranium ore and thorium ore (Category 1) are subject to the requirements for practices in terms of paras 2.1(b) and 2.2(b) of the BSS [2] and require a licence (Ref. [2], para. 2.12).
- Operations in Categories 2 and 3 are subject to the requirements for practices in terms of para. 2.5(b) of the BSS [2], and the degree of control should be matched to the level of exposure or hazard. For operations in Category 2 involving exposures to dust and external gamma radiation, para. 2.27 of the Safety Guide on Occupational Radiation Protection [7] states: "Control, if considered necessary, would include the use of methods to suppress or contain any airborne dusts and general radiological supervision". Authorization in the form of registration may be sufficient for operations in Categories 2 and 3 but, if levels of exposures are high, licensing may be necessary to ensure the required level of control.
- The mining and processing of raw materials in Category 4 are not subject to the requirements for practices and require no authorization.

Natural sources of radiation: action levels

2.4. The regulatory body should specify and declare which mining and processing operations are subject to the recommendations provided in this

Safety Guide so as to ensure that all necessary notifications and applications for authorization are duly submitted to the regulatory body, while avoiding unnecessary submissions. The basis for the identification of operations falling within Categories 2 and 3, including the use of action levels, is described in the Safety Guide on Occupational Radiation Protection [7].

2.5. With respect to operations falling within Category 2, paras 2.24–2.26 of Ref. [7] state:

"Para. 2.5(b)(iii) of the BSS provides for the regulatory [body] to specify other situations involving exposure to natural sources of radiation to be subject to the requirements for practices. The other situations in which exposures to natural sources of radiation at work may need to be considered include:

(a) The mining, milling, handling and use of materials containing elevated levels of natural radionuclides (in addition to those ores from which uranium and thorium are extracted);
(b) The presence of materials in which the activity concentration of natural radionuclides has been increased during processing…

"The regulatory [body] should first undertake an investigation of these situations to determine the extent of the exposures. Where the exposures are considered sufficient to warrant attention, the regulatory [body] should decide whether they should be subject to the requirements for practices.

"…it might be appropriate… to define levels of annual dose or some other quantity above which the requirements would apply. …an appropriate quantity to use for these levels would be activity concentration…"

Paragraph 2.27 of Ref. [7] states that activity concentration levels in the range 1–10 Bq/g (of the parent radionuclide) may be appropriate in these situations. Where operations also involve exposure to radon, the radon action level should be used as the basis for determining whether such exposure is subject to the requirements for practices (see para. 2.6).

2.6. With respect to operations falling within Category 3, paras 2.19–2.22 of Ref. [7] state[3]:

[3] In the quotation in this paragraph from the Safety Guide on Occupational Radiation Protection [7], Ref. [11] is ICRP Publication 65, the same as that listed as Ref. [11] in the present Safety Guide.

“…exposures to radon in workplaces other than those covered in para. 2.5(b)(i) [of the BSS] should be subject to the requirements for occupational exposure if the radon concentration exceeds the action level…

“Action levels apply to chronic exposure situations, which are described in Appendix VI of the BSS. The primary purpose of an action level is to define the circumstances under which remedial or protective action should be undertaken. In the case of adventitious exposure to radon, the procedure should be for the regulatory [body] to identify or determine, by means of a survey or otherwise, those workplaces with radon concentrations above the action level. Consideration should then be given to whether the concentrations can reasonably be reduced below the action level. Where sufficient reduction in concentrations cannot reasonably be achieved, the requirements for practices should be applied. Thus, at this stage the numerical value of the action level has a conceptually different significance than that initially given to it. It is no longer to be used as the basis for a decision on intervention, but as the basis for a decision to consider the exposures to be arising from a practice.

“The action level for radon in the workplace is given in the BSS as a yearly average concentration of 1000 Bq/m^3, which would normally equate to an annual effective dose of about 6 mSv. This value is the midpoint of the range of 500–1500 Bq/m^3 recommended by the ICRP [11], and some regulatory [bodies] may therefore wish to use a lower level than that specified in the BSS. It should be noted that the range of values given by the ICRP was based on an assumed equilibrium factor between radon and its progeny of about 0.4. There is practical advantage in adopting a single value for the action level which applies to all situations irrespective of the equilibrium factor. Nevertheless, although not explicitly stated in the BSS, other action levels may be appropriate if the equilibrium factor is significantly different from this, which may be the case in some mines.

“In workplaces, particularly in underground mines, there can be large variations in space and time of the concentration of radon and its progeny. This should be taken into account when the decision is made as to whether the action level is exceeded.”

In a regulatory decision on the radon action level to be used, the equilibrium factor between radon and its progeny, if known, should be taken into account. For example, if the equilibrium factor is 0.8, then, in theory at least, a value for the action level of 500 Bq/m^3 may be more appropriate than a value of 1000 Bq/m^3.

Occupational exposure

2.7. The term 'occupational exposure' has been used by the ILO to refer to an exposure of a worker which gives rise to a dose that is received or committed during a period of work [12]. However, the BSS (Ref. [2], paras 1.4 and 2.17) provide for the exclusion of exposures whose magnitude or likelihood is essentially unamenable to control, and for the exemption of those practices and sources within a practice that give rise to radiation risks that are sufficiently low as to be of no regulatory concern. In order that protective and preventive actions can be made focused and effective, the definition of occupational exposure is more limited, namely: "All exposure of workers incurred in the course of their work, with the exception of excluded [from the Standards] exposures and exposures from exempt [by the Standards] practices or exempt sources." It is these 'occupational exposures' that should be considered the responsibility of the management (Ref. [7], para. 2.6) — that is, exposures in the first three categories defined in para. 2.2.

NOTIFICATION AND AUTHORIZATION

Notification

2.8. Paragraph 2.10 of the BSS [2] states:

"Any legal person intending to carry out any of the actions specified under the General Obligations for practices of the Standards… shall submit a notification to the [regulatory body] of such an intention[6]…

[6] Notification alone is sufficient provided that the normal exposures associated with the practice or action are unlikely to exceed a small fraction, specified by the [regulatory body], of the relevant limits, and that the likelihood and expected amount of potential exposure and any other detrimental consequence are negligible."

The 'actions' referred to in this requirement include all mining and processing operations in Categories 1–3 in para. 2.2.

Licensing

2.9. Paragraph 2.12 of the BSS [2] states: "The legal person responsible for any… mine or mill processing radioactive ores… shall apply to the [regulatory body] for an authorization which shall take the form of a licence." This requirement applies to all operations in Category 1 of para. 2.2. For operations in Categories 2 and 3 of para. 2.2, licensing may also be necessary if levels of exposures are high and specific control measures for radiation protection are required to be taken (see para. 2.3).

2.10. Licences for facilities for the mining and processing of uranium ore or thorium ore (Category 1 of para. 2.2) should cover the following work activities:

(a) Exploration involving possible exposure to radiation;
(b) Removal of radioactive ore from a site (e.g. for metallurgical testing and evaluation) in an amount exceeding the exemption criterion specified by the regulatory body;
(c) Excavation of radioactive ore from a site, including a test mine, for evaluation or delineation of the ore body;
(d) Siting, construction or operation of a mine or processing facility;
(e) Transport of the product of a mine or processing facility;
(f) Decommissioning or closure of a mine or processing facility;
(g) Radioactive waste management.

Some or all of these activities may be authorized by means of a single licence at the discretion of the regulatory body.

2.11. For the suspension or cessation of operation of a facility for the mining and processing of uranium ore or thorium ore (Category 1 of para. 2.2), the regulatory body may, on request by the licensee, issue a permit whose form will depend on the terms of national legislation.

2.12. Licences for the mining and processing of raw materials other than uranium ore or thorium ore for which specific control measures for radiation protection are required (Categories 2 and 3 of para. 2.2) should provide for the control of some of the work activities described in para. 2.10; in particular, siting, construction, operation, management of waste and the decommissioning or closure of the mine or processing facility should be considered for control.

2.13. If, on the premises of a mine or processing facility, there is a radioactive source, other than a raw material, that the regulatory body has not designated as suitable for registration or exemption, a licence is required for its possession and use (Ref. [2], para. 2.12).

Registration

2.14. The authorization of operations in Categories 2 and 3 of para. 2.2 may take the form of a registration where levels of exposures are low and where registration is sufficient to ensure the necessary level of control (see para. 2.3). Registration should provide for the conditions of occupational exposure to be reviewed periodically or in the event of a change in the process that could significantly affect exposures.

APPLICATION FOR AUTHORIZATION

2.15. An authorization for the removal or excavation of ore or for the siting, construction, operation, decommissioning or closure of a mining or processing facility should be granted only if the regulatory body is satisfied that the applicant has the capability to comply with the requirements for protection and safety. Such requirements include measures for the protection of the health and safety of workers and the public, and for the maintenance of security against theft or loss of radioactive material and unauthorized entry to premises.

2.16. An applicant for a licence for a uranium or thorium mine or processing facility (Category 1 of para. 2.2) is required to provide relevant information in support of the application and to make an assessment of the nature, magnitude and likelihood of exposure attributed to the source (Ref. [2], para. 2.13(a) and (c)). If the potential for exposure is greater than the level, if any, specified by the regulatory body, a safety assessment is required as part of the application (Ref. [2], para. 2.13(d)). This should include the specific information listed under the applicable categories as given in paras 2.17–2.24.

Removal of uranium ore or thorium ore from a site

2.17. An applicant for a licence to remove uranium ore or thorium ore from a site should provide information on the following:

- — mining leases;
- — types of work activities and types of equipment involved;
- — quantities of uranium and/or thorium to be removed with the ore;
- — transport of the ore;
- — estimates of exposures and doses for workers;
- — measures for radiation protection;

— procedures for dealing with accidental releases of radioactive or non-radioactive contaminants to the environment;
— proposed decommissioning plans.

Excavation of uranium ore or thorium ore from a site

2.18. An applicant for a licence to excavate uranium ore or thorium ore from a site should provide information on the following:

— proposed work activities;
— mining leases;
— the site, including geology, mineralogy and extraction techniques;
— measures for radiation protection;
— procedures for dealing with accidental releases of contaminants;
— water treatment;
— stockpiles of ore and waste rock;
— overburden;
— estimates of workplace exposures and individual doses for workers;
— impacts on public health and safety;
— proposed decommissioning plans.

Siting or construction of a uranium or thorium mine or processing facility

2.19. An applicant for a licence to site or construct a uranium or thorium mine or processing facility should provide information on the following:

— the siting or construction (general plan);
— the conceptual design of the mining or processing facility;
— the siting of tailings and the storage facilities for ore and waste rock (a detailed description as required by the regulatory body);
— radiation protection measures;
— methods for monitoring air quality;
— estimates of workplace exposures and individual doses for workers;
— procedures for accident prevention;
— the management of effluents;
— environmental impacts.

Information should be provided on the planned critical evaluation of equipment and facilities in the commissioning phase to confirm the effectiveness of the intended engineering control measures.

Operation of a uranium or thorium mine or processing facility

2.20. An applicant for a licence to operate a uranium or thorium mine or processing facility should provide information on the following:

— the mine or processing facility itself (a detailed description as required by the regulatory body);
— mining methods and engineering controls for radiation protection, including methods of shielding, ventilation and control of air quality;
— a description of programmes for operational radiation protection, including equipment and facilities;
— estimates of workplace exposures and individual doses for workers;
— emergency action plans, as appropriate;
— details of the effluent management system and waste management system;
— the transport of processed ore;
— security measures;
— other relevant information.

2.21. In accordance with paras 2.11 and 5.10 of the Safety Guide on Management of Radioactive Waste from the Mining and Milling of Ores [10], and depending on national legislation (Ref. [13], para. 2.4(13)), the applicant may also be required to demonstrate that financial resources will be available for decommissioning or closure.

Changes to the design or operation of a uranium or thorium mine or processing facility

2.22. Paragraph 2.16 of the BSS [2] states that "…licensees shall notify the [regulatory body] of their intentions to introduce modifications to any practice or source for which they are authorized, whenever the modifications could have significant implications for protection or safety, and shall not carry out any such modification unless specifically authorized by the [regulatory body]." Accordingly, any change to the design or operation of a uranium or thorium mine or processing facility that may lead to a significant increase, as defined by the regulatory body, in occupational exposures or public exposures requires referral to the regulatory body for formal review, assessment and amendment of the authorization (Ref. [13], paras 5.6 and 5.11).

2.23. An application to suspend or cease the operation of a uranium or thorium mine or processing facility should provide the reasons for the suspension or cessation, together with the plans and programmes for short term and long term control measures for radiation protection and security measures during the suspension or post-cessation period.

Decommissioning or closure of a uranium or thorium mine or processing facility

2.24. An applicant for a licence to decommission or close a uranium or thorium mine or processing facility should provide the following:

— a plan and schedule of all work activities;
— confirmation that the necessary financial resources are available;
— a description of the possible impacts on the health and safety of workers and the public, and the radiation protection measures to be taken;
— estimates of workplace exposures and individual doses for workers;
— a plan for short term and long term surveillance of radiation levels, including the nature and extent of necessary institutional controls.

Further guidance is given in Ref. [10].

2.25. An applicant for an authorization for a mine or processing facility handling raw materials other than uranium ore or thorium ore (Categories 2 and 3 of para. 2.2) should provide information, as determined on a case by case basis, on:

— the radiation hazards and any measures to control them,
— the supervision measures necessary,
— any other relevant information as required by the regulatory body.

The need for any of the information listed under the categories given for uranium ore and thorium ore in paras 2.17–2.24 should be reviewed and such information should be supplied as appropriate.

RESPONSIBILITIES

2.26. The responsibility for adopting and ensuring the observance of the recommendations provided in this Safety Guide lies with the registrant or licensee (the “legal person”, as defined in the BSS [2]) unless otherwise stated. In cases where the registrant or licensee does not directly manage the work activities relating to the mining and processing facility, day to day responsibility may be delegated to the employer or to the management of the facility, but accountability remains with the registrant or licensee. The term 'employer' is used in this Safety Guide for convenience to indicate the organizational management, irrespective of whether or not the employer is the registrant or licensee.

2.27. The responsibilities of employers and workers in the mining and processing facilities covered by this Safety Guide are in principle no different from those in any other authorized practice, and as such are described in paras I.1–I.14 (Appendix I) of the BSS [2] and in the Safety Guide on Occupational Radiation Protection (Ref. [7], paras 2.33–2.39). Further guidance is provided in Appendix I of this Safety Guide.

INSPECTION AND NON-COMPLIANCE

2.28. Paragraphs 1.5 and 1.10–1.14 of the BSS [2] state:

"The [regulatory body]… shall be responsible for the enforcement of the Standards."

....

"The principal parties [i.e. the registrant or licensee and the employer] shall permit duly authorized representatives of the [regulatory body]… to inspect their protection and safety records and to carry out appropriate inspections of their authorized activities.

"In the event of a breach of any applicable requirement of the Standards, principal parties shall, as appropriate:

(a) investigate the breach and its causes, circumstances and consequences;
(b) take appropriate action to remedy the circumstances that led to the breach and to prevent a recurrence of similar breaches;
(c) communicate to the [regulatory body]… on the causes of the breach and on the corrective or preventive actions taken or to be taken; and
(d) take whatever other actions are necessary as required by the Standards.

"The communication of a breach of the Standards shall be prompt…

"Failure to take corrective or preventive actions within a reasonable time in accordance with national regulations shall be grounds for modifying, suspending or withdrawing any authorization that had been granted by the [regulatory body]…

"Wilful breach of, attempted breach of or conspiracy to breach any requirement of the Standards shall be subject to the provisions for such infractions by the appropriate national legislation of the State, or by the [regulatory body]…”

2.29. Requirements in respect of legal and governmental infrastructures for regulatory inspection and enforcement are established in Ref. [13], paras 5.12–5.24. The enforcement system should include the appointment of qualified inspectors and the use of suitable monitoring equipment and facilities.

2.30. The employer’s records available for inspection should include any document or record, including workers’ dose records, pertaining to aspects of health and safety, security or environmental protection for the authorized mine or processing facility, with the exception of workers’ medical records, which should be kept confidential (Ref. [7], paras 7.9 and 7.12).

2.31. The employer should afford the inspector all reasonable co-operation and assistance in the execution of his or her duties.

2.32. No person should knowingly make a false or misleading statement to, or deliberately obstruct or hinder, an inspector in the course of his or her duties.

2.33. The inspector should discuss with the employer the findings of an inspection before leaving the premises and should advise the employer and workers, through their representatives where appropriate, to take urgent corrective action in a facility or operation when, in the opinion of the inspector, such action is necessary for the health and safety of the workers or the public or for the protection of the environment.

2.34. As soon as practicable, the inspector should provide the employer with the written findings of the inspection, specifying any necessary corrective measures to be taken in respect of health, safety, security or the environment. Where appropriate, the regulatory body is required to issue a directive enforcing compliance with such corrective measures by the employer (Ref. [13], para. 5.19).

2.35. For mining and processing facilities that are subject to registration, the inspections carried out by the regulatory body should take the form of periodic reviews to establish that the radiological conditions have not deteriorated to the extent that a change in registration conditions becomes necessary.

3. DOSE LIMITATION

APPLICATION OF THE PRINCIPAL RADIATION PROTECTION REQUIREMENTS

3.1. Radiation exposures resulting from the mining and processing of raw materials covered by this Safety Guide are required to be controlled through a system of radiation protection based on three principal requirements: the justification of practices, the limitation of radiation doses to individuals, and the optimization of protection and safety, as established by the BSS [2]. These requirements, based on recommendations of the ICRP [3], are dealt with more specifically in the Safety Guide on Occupational Radiation Protection [7].

3.2. The requirement of the BSS for the justification of a practice (Ref. [2], para. 2.20) specifies:

> "No practice or source within a practice should be authorized unless the practice produces sufficient benefit to the exposed individuals or to society to offset the radiation harm that it might cause; that is: unless the practice is justified, taking into account social, economic and other relevant factors."

This requirement applies to a class of undertaking such as mining or manufacturing. This Safety Guide provides no further guidance on the justification of such operations, as decisions on justification are outside the scope of this Safety Guide and will be taken before applying the Safety Guide.

3.3. In terms of the requirement of the BSS for dose limitation (Ref. [2], para. 2.23), exposures of workers are controlled by the application of occupational dose limits. It is required that neither the total effective dose nor the total equivalent dose to relevant organs and tissues, caused by the possible combination of exposures from any work activities associated with the mining or processing operation, exceed any relevant dose limit specified in paras 3.5 and 3.6, except in the special circumstances provided for in para. 3.7.

3.4. The requirement of the BSS for the optimization of protection and safety (Ref. [2], para. 2.24) specifies:

> "…protection and safety shall be optimized in order that the magnitude of individual doses, the number of people exposed and the likelihood of incurring exposures all be kept as low as reasonably achievable, economic and social

factors being taken into account, within the restriction that the doses to individuals delivered by the source be subject to dose constraints."

Further guidance can be found in Section 4 of the Safety Guide on Occupational Radiation Protection [7].

DOSE LIMITS

3.5. The limits on effective dose for occupational exposure, which apply to the sum of effective doses from external sources in a specified period and committed effective doses from intakes in the same period, are specified in para. II-5 (Schedule II) of the BSS [2] as:

"(a) an effective dose of 20 mSv per year averaged over five consecutive years[38];
(b) an effective dose of 50 mSv in any single year;
(c) an equivalent dose to the lens of the eye of 150 mSv in a year; and
(d) an equivalent dose to the extremities (hands and feet) or the skin[39] of 500 mSv in a year.

[38] The start of the averaging period shall be coincident with the first day of the relevant annual period after the date of entry into force of the Standards, with no retroactive averaging.

[39] The equivalent dose limits for the skin apply to the average dose over 1 cm^2 of the most highly irradiated area of the skin. Skin dose also contributes to the effective dose, this contribution being the average dose to the entire skin multiplied by the tissue weighting factor for the skin."

3.6. Paragraph II-6 (Schedule II) of the BSS [2] (with footnote 39 as above) requires that the following dose limits apply to apprentices of 16 to 18 years of age who are training for employment involving exposure to radiation:

(a) an effective dose of 6 mSv in a year;
(b) an equivalent dose to the lens of the eye of 50 mSv in a year; and
(c) an equivalent dose to the extremities or the skin[39] of 150 mSv in a year."

SPECIAL CIRCUMSTANCES

3.7. Paragraphs 3.10 and 3.11 of the Safety Guide on Occupational Radiation Protection [7] state:

“Even though a practice is justified and is designed and conducted according to good practice, and radiation protection in the practice has been optimized, there may be special circumstances in which occupational exposures still remain above the dose limits. For example, a situation may arise where there is currently some difficulty in changing from the previous limit of 50 mSv in a year and a period of transition is necessary.

“A temporary change to the dose limitation arrangements is permitted by the BSS, subject to a number of conditions, including prior approval by the regulatory [body]. Procedures for varying dose limits in special circumstances are recommended in paras I.50–I.54 (Appendix I) of the BSS, and two alternatives for a temporary change in the dose limitation requirements are specified in para. II-7 (Schedule II) of the BSS.”

VERIFICATION OF COMPLIANCE WITH DOSE LIMITS

3.8. Paragraphs II-10–II-12 (Schedule II) of the BSS [2] state:

“The dose limits specified in Schedule II [i.e. those specified in paras 3.5–3.7 of this Safety Guide] apply to the sum of the relevant doses from external exposure in the specified period and the relevant committed doses from intakes in the same period; the period for calculating the committed dose shall normally be 50 years for intakes by adults…

“For the purpose of demonstrating compliance with dose limits, the sum of the personal dose equivalent from external exposure to penetrating radiation in the specified period and the committed equivalent dose or committed effective dose, as appropriate, from intakes of radioactive substances in the same period shall be used.

“Compliance with the foregoing requirements for application of the… limits on effective dose shall be determined by either of the following methods:

(a) by comparing the total effective dose with the relevant dose limit, where the total effective dose E_T is calculated according to the following formula:

$$E_T = H_p(d) + \sum_j e(g)_{j,\,\mathrm{ing}} I_{j,\mathrm{ing}} + \sum_j e(g)_{j,\mathrm{inh}} I_{j,\mathrm{inh}}$$

where $H_p(d)$ is the personal dose equivalent from exposure to penetrating radiation during the year; $e(g)_{j,\mathrm{ing}}$ and $e(g)_{j,\mathrm{inh}}$ are the committed effective dose per unit intake by ingestion and inhalation for radionuclide j by the group of age g; and $I_{j,\text{ing}}$ and $I_{j,\text{inh}}$ are the intakes via ingestion or inhalation of radionuclide j during the same period; or

(b) by satisfying the following condition:

$$\frac{H_p(d)}{DL} + \sum_j \frac{I_{j,\text{ing}}}{I_{j,\text{ing,L}}} + \sum_j \frac{I_{j,\text{inh}}}{I_{j,\text{inh,L}}} \leq 1$$

where DL is the relevant… limit on effective dose, and $I_{j,\text{ing,L}}$ and $I_{j,\text{inh,L}}$ are the annual limits on intake (ALI) via ingestion or via inhalation of radionuclide j (i.e. the intakes by the relevant route of radionuclide j that lead to the relevant limit on effective dose); or

(c) by any other approved method."

3.9. In the methods described in para. 3.8 for determining compliance with the dose limits, intakes from both inhalation and ingestion of radionuclides are considered. While all significant intakes should be taken into account, ingestion intakes are less likely to be of concern in the mining and processing of raw materials, and are not considered further in the more detailed guidance that follows.

3.10. The inhalation intakes of and the limits on intake for short lived progeny of radon (^{222}Rn) and thoron (^{220}Rn) [4] in the formulas given in para. 3.8 may be expressed in terms of potential alpha energy[5]. The potential alpha energy intake can be determined from measurements of the potential alpha energy concentration in the air (PAEC) and the volume of air inhaled. Alternatively, the intakes and limits on intake in the formulas given in para. 3.8 may be replaced by potential alpha energy exposures and exposure limits (SI unit: $\text{mJ}\cdot\text{h}\cdot\text{m}^{-3}$), in which case, if using the first method described in para. 3.8, the term $e(g)_{j,\text{inh}}$ becomes the committed effective dose per unit exposure rather than per unit intake. Potential alpha energy exposures to radon progeny and thoron progeny may be determined by integrating the PAEC over the exposure time; they may also be determined from the concentrations of radon and

[4] The relevant radon progeny are ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po and the relevant thoron progeny are ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po and ^{208}Tl.

[5] The potential alpha energy of radon progeny and thoron progeny is the total alpha energy ultimately emitted in the decay of radon progeny and thoron progeny through the decay chain, up to but not including ^{210}Pb for progeny of ^{222}Rn and up to stable ^{208}Pb for progeny of ^{220}Rn (see previous footnote). The SI unit of potential alpha energy is the joule (J).

thoron gas in the air by using the following formulas derived from Table A.1 of ICRP Publication 47 [14] and para. 15 of ICRP Publication 65 [11]:

$$P_{RnP} = 5.56 \times 10^{-6} \times t \times F_{RnP} \times C_{Rn}$$
$$P_{TnP} = 7.57 \times 10^{-5} \times t \times F_{TnP} \times C_{Tn}$$

where

P_{RnP}, P_{TnP} are the potential alpha energy exposures to radon progeny and thoron progeny, respectively (mJ·h·m^{-3}),
t is the exposure time (h),
F_{RnP} is the equilibrium factor for radon progeny (often taken as 0.4),
C_{Rn} is the radon gas concentration (Bq/m^3),
F_{TnP} is the equilibrium factor for thoron progeny,
C_{Tn} is the thoron gas concentration (Bq/m^3).

Temporal variations in concentrations of radon or thoron may be taken into account by expressing such concentrations as time weighted averages.

3.11. Inhalation intakes of dusts containing uranium or thorium are usually determined from measurements of the alpha activity associated with airborne dust particles. Details of the dust monitoring and analysis techniques involved are given in Appendix IV.

3.12. In the application of the first verification method described in para. 3.8 to the mining and processing of uranium ore and thorium ore, and taking into account the considerations in paras 3.9–3.11, the total annual effective dose E_T received or committed may be estimated from the following formula:

$$E_T = H_p(d)+H_{RnP}P_{RnP}+H_{TnP}P_{TnP}+H_{ODU}I_{ODU}+H_{ODTh}I_{ODTh}+H_{CU}I_{CU} + H_{CTh}I_{CTh}$$

where

$H_p(d)$ is the personal dose equivalent received from exposure to penetrating radiation during the year (mSv) — a reference depth of d = 10 mm in soft tissue is appropriate for determining the effective dose received by a worker in a mining or processing facility (see Ref. [7], paras 2.44 and 2.46; Ref. [8], paras 2.7 and 3.11).
H_{RnP} is the committed effective dose per unit exposure to radon progeny — 1.4 mSv per mJ·h·m^{-3} (see Table II-II (Schedule II) of the BSS [2]).

H_{TnP} is the committed effective dose per unit exposure to thoron progeny — 0.48 mSv per mJ·h·m^{-3} (see Table II-II (Schedule II) of the BSS [2]).

H_{ODU} is the committed effective dose per unit intake of alpha activity from the inhalation of uranium ore dust — 0.0035 mSv/Bq (see para. 3.13, and Table A-II of the Annex).

H_{ODTh} is the committed effective dose per unit intake of alpha activity from the inhalation of thorium ore dust — 0.0080 mSv/Bq (see para. 3.13, and Table A-IV of the Annex).

H_{CU} is the committed effective dose per unit intake of alpha activity from the inhalation of uranium concentrate; the numerical value depends strongly on the extraction and post-extraction processes, which determine the proportion of the component of lung absorption type S (slow); further guidance is provided in Appendix II.

H_{CTh} is the committed effective dose per unit intake of alpha activity from the inhalation of thorium concentrate; for chemically separated thorium concentrate the value will depend on the chemical form (see Appendix II); for physically separated thorium concentrate (in which it can be assumed that the ^{232}Th decay products are retained) the value will be the same as that for thorium ore dust (H_{ODTh}).

P_{RnP} is the annual exposure to radon progeny as defined in para. 3.10 (mJ·h·m^{-3}).

P_{TnP} is the annual exposure to thoron progeny as defined in para. 3.10 (mJ·h·m^{-3}).

I_{ODU} is the annual intake of alpha activity from the inhalation of uranium ore dust (Bq).

I_{ODTh} is the annual intake of alpha activity from the inhalation of thorium ore dust (Bq).

I_{CU} is the annual intake of alpha activity from the inhalation of uranium concentrate (Bq).

I_{CTh} is the annual intake of alpha activity from the inhalation of thorium concentrate (Bq).

3.13. For inhalation of ore dust, the committed effective dose per unit intake of alpha activity depends on the physical and chemical characteristics of the dust and on its radionuclide content. For instance, there is a strong dependence on the lung absorption types for the individual nuclides [15]. The values of H_{ODU} and H_{ODTh} given in para. 3.12 are calculated using the following simplifying assumptions:

— The activity median aerodynamic diameter (AMAD) of the dust particles is the default value of 5 μm [16];
— The radionuclides are in the least soluble form listed in Table II-V (Schedule II) of the BSS [2];
— The ore body, and thus the dust at the time of exposure, is in radioactive equilibrium.

When establishing a monitoring and assessment programme for the verification of compliance (see para. 4.26), consideration should be given to the validity of these assumptions. Should circumstances or investigation suggest that any of the assumptions are invalid or unacceptable, appropriate modifications or alternatives for a more accurate assessment should be carefully considered.

3.14. In the application of the second verification method described in para. 3.8 to the mining and processing of uranium ore and thorium ore, and again taking into account the considerations in paras 3.9–3.11, the following condition should be satisfied:

$$\frac{H_{\mathrm{p}}(d)}{DL}+\frac{P_{\mathrm{RnP}}}{P_{\mathrm{RnP,L}}}+\frac{P_{\mathrm{TnP}}}{P_{\mathrm{TnP,L}}}+\frac{I_{\mathrm{ODU}}}{I_{\mathrm{ODU,L}}}+\frac{I_{\mathrm{ODTh}}}{I_{\mathrm{ODTh,L}}}+\frac{I_{\mathrm{CU}}}{I_{\mathrm{CU,L}}}+\frac{I_{\mathrm{CTh}}}{I_{\mathrm{CTh,L}}}\leq 1$$

where $H_{\mathrm{p}}(d)$ is the personal dose equivalent (mSv) from exposure to penetrating radiation during the year, estimated using a reference depth $d = 10$ mm (see para. 3.12); DL is the relevant annual limit on effective dose; $P_{\mathrm{RnP,L}}$, $P_{\mathrm{TnP,L}}$ are the corresponding limits on exposure to radon progeny and thoron progeny, respectively; $I_{\mathrm{ODU,L}}$, $I_{\mathrm{ODTh,L}}$ are the corresponding ALIs for inhalation of ore dust containing uranium and thorium, respectively; and $I_{\mathrm{CU,L}}$ and $I_{\mathrm{CTh,L}}$ are the corresponding ALIs for inhalation of uranium and thorium concentrates, respectively. These limits on exposure and intake are given by the following general formula:

$$P_{x,\mathrm{L}}, I_{x,\mathrm{L}}=\frac{DL}{H_x}$$

where DL is either 20 or 50 mSv (see para. 3.5) and the various values of H_x are as given in para. 3.12. The numerical values of the limits on exposure and intake derived in this way are given in paras 3.15 and 3.17.

3.15. For exposure to radon progeny and thoron progeny, Table II-I (Schedule II) of the BSS [2] specifies the following annual limits on potential alpha energy exposure corresponding to the limits on effective dose given in para. 3.5:

— radon progeny: 20 mSv corresponds to 14 mJ·h·m^{-3}
50 mSv corresponds to 35 mJ·h·m^{-3}
— thoron progeny: 20 mSv corresponds to 42 mJ·h·m^{-3}
50 mSv corresponds to 105 mJ·h·m^{-3}.

3.16. For exposure to radon progeny and thoron progeny, potential alpha energy intakes may be used in the formula given in para. 3.14 rather than potential alpha energy exposures (see para. 3.10). Table II-I (Schedule II) of the BSS [2] specifies the following annual limits on potential alpha energy intake corresponding to the limits on effective dose given in para. 3.5:

— radon progeny: 20 mSv corresponds to 17 mJ
50 mSv corresponds to 42 mJ
— thoron progeny: 20 mSv corresponds to 51 mJ
50 mSv corresponds to 127 mJ.

3.17. For inhalation of ore dust, the ALIs given below are derived using the simplifying assumptions given in para. 3.13 (see the Annex for derivation):

— uranium ore dust: 20 mSv corresponds to an alpha activity intake of 5700 Bq
50 mSv corresponds to an alpha activity intake of 14 000 Bq;
— thorium ore dust: 20 mSv corresponds to an alpha activity intake of 2500 Bq
50 mSv corresponds to an alpha activity intake of 6300 Bq.

If the ore body (and thus the ore dust at the time of exposure) is far from radioactive equilibrium, the ALIs should be calculated using the actual radionuclide ratios. Similarly, if investigations show any other assumptions in para. 3.13 to be invalid, consideration should be given to making a more detailed calculation.

3.18. The formulas given in paras 3.12 and 3.14, with the non-applicable terms omitted, may be used in the application of the verification methods to the mining and processing of raw materials other than uranium ore and thorium ore.

3.19. If thorium is being concentrated from an ore containing both thorium and uranium, the limits on intake for the thorium may need to be modified to take account of the presence of uranium, and vice versa. The limits on intake for mixed uranium and thorium concentrates should be calculated on the basis of dose conversion factors derived in accordance with the method described in Appendix II. If the U/Th ratio is unknown, a conservative approach is to assume that the material contains only thorium.

3.20. The question of the chemical toxicity versus the radiotoxicity of uranium has been reviewed recently in ICRP Publication 78 [15]. For reasonably soluble uranium compounds (Types F and M), damage to the kidneys caused by the chemical toxicity is more important than the radiological effects.

4. RADIATION PROTECTION PROGRAMME

GENERAL

4.1. Radiation protection is only one element in ensuring the overall health and safety of workers in operations in the mining and processing of raw materials. The radiation protection programme (RPP) should be established and managed in close co-operation with those responsible for other areas of health and safety such as industrial hygiene, industrial safety and fire safety.

4.2. The scope, structure and content of the RPP for operations in the mining and processing of raw materials should be based on the general guidance provided in Section 5 of the Safety Guide on Occupational Radiation Protection [7]; details relevant to the RPP for operations in the mining and processing of raw materials are given in Appendix III. Specific information on radiation monitoring techniques is provided in Appendix IV.

4.3. The Safety Guide on Occupational Radiation Protection (Ref. [7], para. 5.3) states: "The characteristics of exposure situations may vary considerably depending on the type of installation concerned… It is important to ensure that the RPP is well adapted to the situation." Considerations specific to operations in the mining and processing of raw materials that it may be appropriate to incorporate into the RPP include the following:

(a) The organizational measures aimed at identifying and ensuring the availability of qualified experts (see Appendix III, para. III.3) should be in accordance with the type of mining or processing operation. In underground mines, for instance, special reference may need to be made to the role of the ventilation officer and to the need for close collaboration between the ventilation officer and the radiation protection officer where these are not the same person. Further details are given in paras 4.4–4.11.

(b) Local operating instructions (see Appendix III, paras III.11–III.15) should, in appropriate situations such as for underground mines, include particular reference to the maintenance of adequate quality and quantity of ventilation air and the control of ventilation, including the provision for the use of alternative means if the ventilation system fails.

(c) In classifying areas as controlled or supervised (see Appendix III, paras III.6–III.10), it may be appropriate in some underground mines to designate the entire area as a controlled area for practical purposes.

(d) In specifying access controls for controlled areas underground or in open pits (see Appendix III, para. III.9), normal means of access control such as cards, tags and supervision may be the best practical option; more comprehensive controls, such as those in place for security purposes, may be appropriate for processing facilities or factories located above ground — these could take the form of physical barriers, including locks and interlocks.

(e) The arrangements for the monitoring of workers and the workplace (see Appendix III, paras III.16–III.20), including the acquisition and maintenance of instruments for radiation protection, should be focused on the significant sources of exposure identified in the prior radiological evaluation of the mining or processing operation (e.g. radon and thoron and their progeny, dust containing uranium and thorium) and on the adoption of appropriate and practicable monitoring strategies; further details are given in paras 4.12–4.35).

(f) The education and training programme (see Appendix III, paras III.23–III.28) should include topics specific to radiological protection in operations in the mining and processing of raw materials; depending on the type of mining or processing operation, these topics may include some or all of the following:

    (i) The properties of and hazards associated with uranium and thorium; radon, thoron and their progeny; and dust containing uranium and thorium.

    (ii) Measurement of the concentrations of uranium bearing and thorium bearing dust, the concentrations of radon and thoron and their progeny, and the levels of beta and gamma radiation; and any applicable guidelines and criteria.

(iii) The effect of smoking on risks associated with exposure to radon and, for this reason, the need for workers to be advised against smoking.

(iv) The functioning and purpose of the ventilation system, the importance of following the ventilation officer's recommendations and the need for the ventilation system to be operated.

(v) The need for the immediate reporting of any breakdown of the ventilation system to the supervisor or the ventilation officer.

(vi) The purpose and methods of controlling and suppressing radioactive dust at the mining or processing facility.

(vii) The location of escape routes and the plans for evacuating the mining or processing facility in an emergency.

QUALIFIED EXPERTS

4.4. The RPP for a licensed mining or processing facility should specify the need for qualified expert services in the fields of:

(a) Radiation protection and dosimetry (see Appendix III, para. III.4);
(b) Ventilation (where appropriate, e.g. in underground mines);
(c) Occupational medicine (see Section 6 and Appendix VI);
(d) Industrial safety.

4.5. The employer should ensure that the relevant services of qualified experts are provided and that the persons providing such services relating to radiological protection work in close co-operation and maintain close working contacts with persons responsible for the control of non-radiological hazards. Qualified experts in radiation protection and ventilation are normally employed directly, although this is not always the case. In any case, the employer should appropriately designate such experts. In this Safety Guide the two types of expert are designated by the terms 'radiation protection officer' and 'ventilation officer'. The employer should similarly designate the qualified expert in occupational medicine.

4.6. The functions of the radiation protection officer and the ventilation officer are interrelated in many ways and may for the operation of some plant or facilities be combined into a single function. Where the responsibilities are divided between two officers, these two officers should maintain a close liaison.

4.7. The radiation protection officers and the ventilation officers should report directly to the senior representative of the employer at the mine or processing facility, who has overall responsibility for operations.

4.8. The radiation protection officers and the ventilation officers should be provided with adequate equipment and staff to fulfil their functions as outlined in para. III.4 (Appendix III) and para. 4.11, respectively.

4.9. The effectiveness of the control measures implemented by the radiation protection officers and the ventilation officers should be assessed periodically by senior management.

Ventilation officer

4.10. The ventilation officer should be a qualified expert who, by virtue of certification by an appropriate board or society, a professional licence or academic qualifications and experience, is duly recognized as having expertise in the design and operation of mining and industrial ventilation systems.

4.11. The ventilation officer should:

(a) Advise the management on all matters relating to ventilation systems and air purification systems;
(b) Ensure the proper operation of the ventilation system as designed and should initiate modifications as the development of the mine necessitates;
(c) Ensure that measurements of air flows and velocities are made in accordance with good practice for ventilation;
(d) Ensure that properly calibrated instruments are used;
(e) Conduct dust sampling and control programmes in conjunction with the radiation protection officer (see Appendix III, para. III.4(d));
(f) Participate in training programmes and should develop or approve all training material relating to ventilation and dust control;
(g) Be familiar with the properties of radon and thoron and their progeny, where applicable.

MONITORING AND DOSE ASSESSMENT

Monitoring for operational control

4.12. Physical measurement of the parameters relevant for radiation protection, for example, radon concentrations in an underground mine, provides diagnostic information necessary for ensuring radiation safety. It provides a method of quickly detecting departures from normal operating conditions and indicating that corrective action should be taken. The RPP should include provisions for monitoring the performance of control equipment, such as ventilation components, and for identifying deficiencies in design or in routine operations.

4.13. The RPP should also facilitate the prediction and explanation of trends and of the significant source terms as the operation develops. This is important in the planning of mitigatory measures in the longer term. It is an essential part of the optimization of radiation protection, particularly in mining.

4.14. During initial operation, comprehensive surveys of external gamma radiation, airborne radioactive dust, radon and its progeny, and surface contamination levels should be conducted.

4.15. In open pit mines stagnant atmospheric conditions caused by temperature inversions can adversely affect the radiation exposure of the workforce. Such conditions should be monitored.

4.16. In deciding on the frequency and scale of the monitoring in a particular controlled or supervised area, the dose rates and concentrations of contaminants and their fluctuations over time should be taken into account. It is important that the radiation protection officer and the ventilation officer liaise closely in the execution of the monitoring programme. Further guidance is given in three IAEA Safety Guides [7–9] and in ICRP Publications 75 and 78 [6, 15].

Measurements of external gamma dose rates

4.17. For the purposes of engineering control and in conditions of high dose rates as specified by the regulatory body, in conducting external gamma radiation surveys in working areas of mines, processing facilities and associated waste management areas:

(a) The frequency of measurements should be specified in the local operating instructions and determined in the light of historical results and expected dose rates and their variability;
(b) Each working area should be surveyed, with particular attention paid to fixed working locations and to other areas where workers may remain for a large part of the day;
(c) Details of the workplaces surveyed and the dose rates determined should be recorded.

Measurements of radon and radon progeny concentrations

4.18. Workplace monitoring for engineering control of concentrations of radon and radon progeny should be undertaken at the intervals stated in the local operating instructions. In setting the frequency of measurements, historical results, expected variations in measurements and the degree of hazard should be taken into account. The frequency should be increased if:

(a) Measured concentrations exceed the usual range in the individual workplace;
(b) Major changes are made to the ventilation system, the layout of the mine or the method of mining;
(c) Reference levels are exceeded (see Appendix III, paras III.11(b) and III.14);
(d) The effectiveness of corrective action is to be assessed (see Appendix III, para. III.14);
(e) It is suspected that the ingress of radon has increased.

Measurements of radioactive dust concentration

4.19. In mines and processing facilities for which there is a possibility of receiving significant doses from the inhalation of radioactive dust, regular monitoring for airborne radioactive dust should be performed. In deciding on the frequency of this monitoring, the concentrations of radioactive dust, its size distribution and the potential for its inhalation or ingestion should be taken into account. The monitoring programme for radioactive dust should be described in the local operating instructions. The levels of exposures that are predicted due to the concentrations of radioactive dust will be a key factor in deciding the nature and extent of any individual monitoring programme necessary.

Measurements of surface contamination

4.20. In order to assess the effectiveness of the dust control system and of the measures to control intakes by workers, measurements should be made of removable radioactive surface contamination on structures and equipment in the crushing area and in the final product area of the processing facility. Such measurements should also be made in areas in a mining facility where dust concentrations are significant. Measurements of surface contamination are also necessary for clearance of equipment and scrap (see para. 5.25).

Checking the performance of the ventilation systems

4.21. In addition to the radiological monitoring described above, the performance of the ventilation systems in the mine and the processing plant should be monitored closely by means of appropriate instrumentation.

4.22. Values of the airflows in the mine should be checked, updated and recorded periodically as the mine is developed and extended. These values should also be checked and recorded after any significant change to the ventilation network or equipment.

4.23. Radon concentrations in the air in underground workplaces should be measured at intervals specified in the local operating instructions. The values should be compared with those expected on the basis of the modelling of the source terms and of the buildup of contaminants. Sources of anomalies, such as the recirculation of air from old workings, should be identified and the anomalies remedied.

4.24. The control of auxiliary ventilation in mines can deteriorate rapidly if there is insufficient maintenance of equipment or if poor operating practices develop (see paras 5.4 and 5.5). The consequences of deteriorating ventilation for the exposures to radon progeny may be severe. Systems should therefore be put in place to detect deficiencies promptly so that corrective measures can be taken immediately.

4.25. Measurements should be made of the flow rates at the inlet and outlet of the auxiliary ventilation duct to demonstrate that leakages of air are under control. The delivery of air should be monitored and recorded at regular intervals to ensure that it remains as designed.

Monitoring for the assessment of occupational exposures and doses

4.26. To meet the requirements for limiting radiological risks, as set out in the BSS [2] and summarized in Section 3 of this Safety Guide, the employer should develop a programme for the individual assessment of occupational exposures and doses. The dose assessment programme should demonstrate compliance with the radiation dose limits for individuals; it should also demonstrate that doses are as low as reasonably achievable, economic and social factors being taken into account, and provide information for individual dose records.

4.27. Two approaches — individual monitoring and workplace monitoring — may be used (either as alternatives or in combination where appropriate) to determine exposure levels for the purposes of individual dose assessment. Individual monitoring is a requirement in certain circumstances (see Ref. [2], para. I.33). A detailed discussion of individual monitoring and its interpretation is given in ICRP Publication 78 [15] and in the Safety Guides on dose assessment [8, 9]. Further information on monitoring strategies and the choice of approach to monitoring is provided in Appendix III.

Individual monitoring

4.28. In situations of exposure to external gamma radiation, workers should be provided with individual dosimeters (see Appendix IV) if the dose rates are such as to give rise to doses that represent a significant fraction of the dose limit specified in para. 3.5(a). The exchange period for dosimeters should be determined by considering the levels of workplace exposures and the particular characteristics of the dosimeter. Exchange periods of one to three months are typical. Further details are provided in the Safety Guide on Assessment of Occupational Exposure Due to External Sources of Radiation [8].

4.29. In situations of exposure to radionuclides taken into the body, consideration of the need for dosimetric assessments for individuals should take into account the working conditions, individual working patterns and tasks, the likely doses and any action levels specified by the regulatory body.

4.30. Personal monitoring devices are available for situations of internal exposure, such as alpha dosimeters for measurements relating to radon or radon progeny and personal air samplers for measurements relating to radioactive dust (see Appendix IV and Refs [9, 17]). However, these are generally more expensive than a workplace monitoring system and they may be impracticable to wear in the mining environment. Dust concentrations in mines can often be kept low enough to avoid the need for individual monitoring using personal samplers, but the need for such monitoring should be examined more closely in dusty areas involving uranium and thorium products (e.g. yellow cake drying and packaging areas), particularly during maintenance operations where exposures may be unusually high.

4.31. For groups of workers in mines who have similar work patterns (for instance drillers, electricians and other service personnel) and who are unlikely to receive doses approaching the dose limit specified in para. 3.5(a), it may be possible to establish average exposures and dose rates by means of individual monitoring of a selected subset of the group. This information may then be combined with attendance records to estimate the individual doses for all members of the group.

4.32. Bioassay measurements such as urine analysis, faecal analysis, breath measurements and in vivo monitoring should be considered for certain monitoring applications in the mining and processing of raw materials. This may be the case if there is concern that personal air sampling to assess doses from intakes of radionuclides, where used, may be insufficiently reliable or inaccurate, in particular situations such as those involving workers in areas where ambient concentrations of airborne radionuclides might be unusually high. In choosing the method or combination of methods, the purpose of the monitoring (i.e. routine or special), the working environment, the physical and chemical forms of the radioactive materials and the practicability of measurement should be taken into account. For example:

— Urine analysis is the primary bioassay procedure for routine monitoring for intakes of uranium, but is generally not sufficiently sensitive for routine monitoring for intakes of thorium;
— Faecal analysis is inappropriate for routine monitoring in operations in the mining and processing of raw materials, but may be used for special monitoring to detect the passage through the gastrointestinal tract of unabsorbed uranium or to determine intakes of thorium;
— Lung counting may be used to detect possible inhalation and retention in the lung of uranium in chemical forms of low solubility (see Annex VIII of Ref. [18]) and to determine intakes of thorium by counting photons from ^{228}Ac, ^{212}Pb and ^{208}Tl; however, lung counting needs to be performed at off-site locations equipped with specialized equipment and highly trained personnel and therefore should be considered only for special monitoring, for instance, when the results of routine monitoring indicate a significant and chronic exposure;

— The measurement of thoron in breath may be useful as an on-site screening technique in the monazite and thorium industries to identify individual workers with elevated thorium lung burdens that may need special monitoring by lung counting.

4.33. Further information on individual monitoring for internal exposure of workers, including the advantages and limitations of the main measurement techniques, is given in ICRP Publication 78 [15] and the Safety Guide on Assessment of Occupational Exposure Due to Intakes of Radionuclides [9].

Workplace monitoring

4.34. When workplace monitoring combined with a knowledge of occupancy times is used for individual dose assessments (see Appendix III, para. III.17):

(a) The locations at which workplace monitors are deployed for measuring contaminant concentrations in air should be selected to be representative of the air breathed by workers, particularly where workers move through areas with differing exposure rates;
(b) Instrumentation used to measure dose rates and contaminant concentrations should be calibrated and maintained regularly under a quality assurance programme as specified in the local operating instructions;
(c) Where appropriate, the ambient conditions of humidity and temperature should be monitored so as to be able to estimate their influence on the results of the dose assessment;
(d) Where grab sampling is used, it should be demonstrated that the samples are representative of average ambient conditions — as a method, it is only appropriate in environments for which conditions are known to be generally stable;
(e) Records of the period of time spent at each work location should be maintained, with a degree of detail as specified in the local operating instructions;
(f) It may be appropriate to undertake occasional individual monitoring to verify that the results obtained are representative.

4.35. The total dose received by an individual may be assessed using the results of workplace monitoring by separately assessing and summing the internal and external components of dose. The internal exposure (to be used in the assessment of the internal component of the dose) may be determined using the sum of the products of the time spent at each location and the measured concentrations of contaminants at these locations. The external component of the dose may be assessed from the sum of the products of the time spent at each location and the dose rates at these locations.

5. ENGINEERING AND ADMINISTRATIVE PROTECTION MEASURES

GENERAL

5.1. Control measures such as quality in design, installation, maintenance, operation, administrative arrangements and instruction of personnel should be used to the maximum extent possible before personal protective equipment for the safety and protection of workers is used. In circumstances in which control measures are not sufficient to provide safe working conditions, or in circumstances in which emergency work has to be carried out, protective equipment should be provided to restrict the exposures of the workers.

5.2. Adequately designed and properly controlled ventilation systems are the most effective means of minimizing the exposure to airborne radioactive substances in underground mines and in processing plants. In underground mines surface coatings and/or barriers may also be effective in restricting exposure to radon and its progeny.

VENTILATION

5.3. The primary ventilation system in a mine provides fresh air to the workplaces and dilutes the contaminants deriving from the mining operations. The design of the ventilation network, including the calculation of values of the air flows in all shafts, tunnels and galleries, is the primary responsibility of the mine management and the ventilation officer.

5.4. In some cases the fresh air supplied by the primary ventilation system is not adequate to ventilate particular workplaces. In these circumstances auxiliary ventilation is commonly supplied to the affected workplaces through flexible ducts. The positioning of auxiliary ventilation ducts should be such as to avoid recirculating eddies of contaminated air.

5.5. As discussed in paras 4.21–4.25, the proper operation of the primary and auxiliary ventilation systems as the mine is developed and extended should be ensured. The employer should put in place a programme of inspection and maintenance of ventilation equipment, including main fans, auxiliary fans and heating or cooling systems. This programme should be documented and recorded.

5.6. The design of the ventilation system should be an integral part of the mine planning and development process with the objective of achieving, where practicable, a 'one pass' or parallel ventilation system to ensure good air quality and to minimize the buildup of radon.

5.7. For the effective operation of primary and auxiliary ventilation systems in mines:

(a) Air intakes and exhausts should be separated to the extent practicable.
(b) For the health and safety of workers, every workplace should be supplied with air of a quantity and quality sufficient to ensure that exposure to dust and to radon and its progeny is minimized.
(c) Primary systems for mine ventilation and dust control should preferably be operated continuously; if the continuous operation of these systems is not practicable, the regulatory body may authorize intermittent operation subject to (d) below.
(d) When the ventilation system has been changed, has failed or has been shut down, workers should be allowed to return to their workplaces only after the ventilation system has been restarted and appropriate monitoring has been done to ensure that the concentrations of airborne contaminants have been reduced to acceptable levels.

Subject to (a)–(c) above being satisfied, there may be some capacity to optimize the equilibrium factor for radon progeny.

5.8. The employer should take measures to deter unauthorized entry to any underground area within a mine that is not ventilated. In the event that the ventilation system is not in operation, essential maintenance services necessary to ensure the operation of equipment or machinery may be carried out provided that all practicable measures are taken to limit the radiation doses received by the workers engaged in the maintenance operation.

5.9. The local operating instructions should specify the actions to be taken in the event that a ventilation system underground or in the process plant fails in any way.

5.10. The location of fixed work stations in return airways or in areas of high external radiation should be avoided. Where appropriate, operator booths with a filtered air supply may be used in these circumstances to provide the necessary protection.

DUST CONTROL

5.11. In most operations in the mining and processing of raw materials, measures are taken for dust control to protect workers against hazards associated with non-radioactive dust. These measures generally restrict the airborne concentrations of radioactive dust sufficiently to meet the requirements for dose limitation as stated in Section 3.

5.12. To ensure that the methods for the control of dust in mines and processing facilities are in place and are adequate, programmes for the sampling and control of dust should be formalized. The following measures should be taken:

(a) The generation of dust in operations should be minimized by the use of appropriate mining techniques such as the use of proper blasting patterns and timing, the use of water and other means of suppressing dust and the use of appropriate equipment.
(b) Where dust is generated, it should be suppressed at source. Where necessary and practicable, the source should be enclosed under negative air pressure. Air may have to be filtered before being discharged to the environment.
(c) Dust that has not been suppressed at source may be diluted to acceptable levels by means of frequent changes of air in the working area. Again, the exhaust air may have to be filtered before being discharged to the environment.
(d) Care should be taken to avoid the resuspension of dust as a result of high air velocities.
(e) Where methods of dust control do not achieve acceptable air quality in working areas, enclosed operating booths with filtered air supplies should be provided for the workers.

CONTROL RELATED CONSIDERATIONS FOR THE PROCESSING OF RAW MATERIALS

5.13. The first consideration in the design of facilities for the processing of raw materials should be the containment of the radioactive materials. Radioactive materials that cannot be contained effectively within the process should be controlled by means of ventilation in order to prevent the release of contaminants and to minimize occupational exposure.

5.14. The design and operation of crushing and screening plants should be such as to keep the release of contaminants as low as practicable.

5.15. The design of the concentrator should be such as to minimize the generation of airborne or liquid contaminants.

5.16. In the design of processing plants, aspects that prevent the buildup of contamination should be considered. The design should facilitate maintenance work for the removal of any contaminants that do accumulate.

5.17. During maintenance operations, special care should be taken to control the exposures of individuals that arise from the accumulation of radioactive material in pipes and vessels in the plant due to the formation of sediments and the buildup of scale.

5.18. As far as practicable, concentrated radioactive and toxic materials should be handled with automated equipment in enclosures where negative air pressure is maintained.

5.19. Good housekeeping and cleanliness should always be maintained. The use of paint colours for walls, handrails, equipment, furniture and other objects that are distinctly different from the colours of the materials and products being processed aids good housekeeping and cleanliness.

5.20. Solid, liquid and gaseous wastes from the processing operation should be managed in accordance with procedures approved by the regulatory body for the protection of workers, the public and the environment.

CLEANUP OF SPILLS

5.21. The employer should establish written procedures, including procedures for the cleanup of spills, to be followed in the event of any significant radiation hazard arising from the loss, escape or release of raw material:

— from the mining facility,
— during transport from the mine to a processing facility or
— from facilities for processing and waste management.

5.22. Any spill of radioactive material in a processing facility should be cleaned up as soon as practicable in order to minimize the spread of contamination. The area should be decontaminated by the removal of all loose material where practicable.

RELEASE OF MATERIALS AND EQUIPMENT FROM MINES AND PROCESSING FACILITIES

5.23. Measures for occupational radiation protection to be adopted in the disposal, recycling or repair of contaminated equipment and materials should be consistent with those given in Ref. [7] and should be in accordance with any procedures approved by the regulatory body.

5.24. The initial design of the facility and subsequent modifications should incorporate features that minimize contamination to facilitate eventual decommissioning.

5.25. Materials and equipment should be decontaminated as far as practicable and in accordance with any applicable requirements for clearance or authorized release before being released from the mining or processing facility. Straightforward methods such as washing or vacuum cleaning are often effective.

PERSONAL PROTECTIVE EQUIPMENT

General

5.26. Personal protective equipment should be selected with due consideration of the hazards involved. The equipment should not only provide adequate protection but also be convenient and comfortable to use.

5.27. Examples of personal protective equipment include reinforced clothing, ventilated suits and respirators. Workers who may have to use such equipment should be properly trained in its use, operation, maintenance and limitations.

Respiratory protection

5.28. Employers should not rely on the use of protective respiratory equipment to comply with the radiation dose limits for individuals, except in temporary and unforeseen circumstances. As discussed in paras 5.1 and 5.12, radon and dust should generally be controlled so that protective respiratory equipment is not necessary for routine tasks. Respiratory equipment may nevertheless be needed in emergencies, for repair and maintenance, and in special short term circumstances. Protective respiratory equipment should be used for a specified and limited period of time only.

5.29. If levels of airborne contaminants exceed the relevant reference levels (see Appendix III, paras III.11(b) and III.14), appropriate protective respiratory equipment should be worn by those persons undertaking corrective measures. While corrective measures are being undertaken, the area should be monitored to estimate possible radiation exposures. Employers should withdraw workers from affected areas if continued exposures are such that recommended safe working levels or dose limits are likely to be exceeded.

5.30. Respiratory equipment and its use should conform to the principles set out in Appendix V.

Other personal protective equipment

5.31. The employer should provide coveralls, head coverings, gloves, boiler suits and impermeable footwear and aprons in accordance with the risks of contamination and as necessary and appropriate for the working conditions. Work clothes including gloves and footwear should be provided to every worker whose personal clothing is likely to become contaminated at the mining or processing facility.

5.32. Personal clothing and working clothing should be changed in suitable locker rooms, where appropriate with a washroom in between, to control the spread of radioactive contamination. Individuals should shower and change clothes on leaving contaminated workplaces.

5.33. When contaminated work clothes are stored, laundered or otherwise decontaminated, or disposed of, the employer should put in place measures to prevent the spread of contamination to other persons or workplaces and to minimize the exposures of individuals and the release of contaminants to the environment.

5.34. The employer should provide suitable laundry facilities, boot washes, vacuum systems or other means of decontamination, as necessary.

PERSONAL HYGIENE

5.35. Washing facilities convenient to the place of work should be provided for all workers.

5.36. Sufficient time should be allowed to each worker for the use of the washing facilities before rest and meal breaks and at the end of the shift.

5.37. No person should eat, drink, chew gum or tobacco, smoke or take snuff in working areas where radioactive material could be ingested.

5.38. The employer should provide at the mining or processing facility — at locations that are reasonably accessible to every worker — clean eating areas that are supplied with water, good quality air and hand washing facilities to prevent the intake of radioactive material. These facilities should be designed, monitored and maintained in a manner acceptable to the regulatory body. The workers using these facilities should be instructed in how to prevent contamination.

FIRST AID

5.39. Special precautions should be taken in the cleaning of wounds sustained in areas where concentrated radioactive material is present and wounds caused by contaminated equipment.

5.40. Before entering working areas, cuts and wounds, particularly to the hands, should be properly dressed with waterproof dressings.

5.41. The employer should ensure that workers are provided with first aid training that is specific to the job.

JOB ROTATION

5.42. In mines where there are areas with high levels of radiation exposure, when no other practicable means of control are available, job rotation may be considered in order to restrict the exposure of individual workers. However, the use of this method should be kept to a minimum, and job rotation should never be used as a substitute for the development and use of appropriate methods of radiation control.

6. HEALTH SURVEILLANCE

6.1. Paragraphs I.41 and I.43 (Appendix I) of the BSS [2] state:

"Employers… shall make arrangements for appropriate health surveillance in accordance with the rules established by the [regulatory body].
"Health surveillance programmes shall be:

(a) based on the general principles of occupational health; and
(b) designed to assess the initial and continuing fitness of workers for their intended tasks."

6.2. The main elements of a health surveillance programme should be:

(a) The assessment of the health of workers for the purpose of ensuring that they are fit to undertake the tasks assigned to them;
(b) The establishment and maintenance of confidential medical records;
(c) The arrangements for dealing with accidental exposures and overexposures;
(d) The provision of medical advice to management and workers.

6.3. The occupational physician in charge of the health surveillance of the workforce should be familiar with the biological effects of radiation exposure, the means of control of exposure, and the interpretation of exposure data and dosimetric assessments. He or she should also be familiar with the tasks and the conditions of the workplace, to be able to make judgements about workers' fitness for work — for operations in the mining and processing of raw materials, the occupational physician should visit the working places periodically to be aware of the particular working and environmental conditions. The ILO Technical and Ethical Guidelines for Workers' Health Surveillance [19] provide detailed guidance for the assistance of persons responsible for the design, establishment, implementation and management of programmes for the surveillance of workers' health.

6.4. Health surveillance programmes for operations in the mining and processing of raw materials need be no different in principle from health surveillance programmes for general industrial activities involving occupational exposure to radiation, for which guidance is provided in:

— Appendix VI of this Safety Guide;
— Section 7 of the Safety Guide on Occupational Radiation Protection [7];
— The Safety Report on Health Surveillance of Persons Occupationally Exposed to Ionizing Radiation [20].

Appendix I

RESPONSIBILITIES OF EMPLOYERS AND WORKERS

RESPONSIBILITIES OF EMPLOYERS

I.1. The employer is responsible for controlling the exposure of workers to radiation and radioactive substances. The employer is required to ensure that the external and internal radiation exposures of each worker are controlled within the relevant limits for individuals, and to consult workers, through their representatives if appropriate, on levels of radiation exposure (Ref. [2], para. I.4(a) and (j)).

I.2. The employer should take into consideration the health and safety of workers at all stages in the design and planning of the facility and, before commencing operations, should provide the regulatory body with information on the likely radiation hazards and the methods to be adopted for controlling exposure to radiation and radioactive substances. A prior radiological evaluation of all aspects of the operations is required to be conducted to identify the potential sources of exposure, to make realistic estimates of the doses and to identify the measures necessary for radiological protection (Ref. [2], para. 2.13(c)).

I.3. As specified in para. I.4(b) of the BSS [2], employers "…shall ensure, for all workers engaged in activities that involve or could involve occupational exposure, that… occupational protection and safety [are] optimized in accordance with the relevant principal requirements of the Standards"; in other words, the employer is required to keep the individual and collective doses of workers as low as reasonably achievable, economic and social factors being taken into account.

I.4. The employer should establish a radiation protection programme to optimize the protection of workers and to ensure the effective management of any control measures required. The employer should:

(a) Ensure that the necessary plant and equipment, monitoring devices, personal protective equipment, and washing and first aid facilities are provided;

(b) Maintain and regularly inspect the facilities, plant and equipment and organize the work to ensure that the relevant dose limits are not exceeded;
(c) Ensure that every occupationally exposed worker and supervisor is given appropriate training in radiation protection practices for the operation and is informed of the nature, sources and potential health effects of exposure to radiation and radioactive substances, and of their control by means of the maintenance of proper ventilation and shielding systems, proper personal hygiene and the use of personal protective equipment where applicable;
(d) Ensure, by means of supervision, that workers perform their work in accordance with the provisions of the local operating instructions;
(e) Establish reference levels as necessary, with the actual conditions on site and the requirements of the regulatory body and the BSS [2] taken into account;
(f) Provide for access by any worker to the information in his or her dose record;
(g) Develop and sustain a system that:

    (i) encourages a questioning and learning attitude to protection and safety;
    (ii) discourages complacency on issues such as acting in accordance with policies and procedures;
    (iii) identifies problems affecting the protection and safety of workers and the public or the protection of the environment;
    (iv) clearly identifies the responsibilities of individuals;
    (v) ensures that individuals are suitably trained and qualified;
    (vi) establishes clear lines of authority for decision making;
    (vii) aids consultation and co-operation with workers, through their representatives if appropriate;

(h) Establish quality assurance programmes which provide, as appropriate, adequate assurance that the requirements relating to protection and safety are satisfied, and that quality control mechanisms and procedures for reviewing and assessing the overall effectiveness of measures for protection and safety are in place;
(i) Report to the appropriate regulatory body any accidental or unscheduled release of radioactive material from the facility or within it, and any information revealing abnormal degradation, weakening or incipient failure of any structure, system or component, where such release, degradation, weakening or failure could constitute or contribute to a

significant radiological risk to the health and safety of workers or could have a significant radiological impact on the environment;

(j) Facilitate the transfer of a worker's dose record to the new employer if the worker changes jobs;

(k) On being released from further regulatory obligations after the termination of operations, transfer to the regulatory body all records relating to radiation exposure.

I.5. To fulfil the requirements and recommendations specified in paras I.1–I.4, the employer should establish detailed control measures. The employer should:

(a) Conduct a commissioning survey or detailed examination of new or significantly modified equipment and installations prior to their becoming operational, a principal purpose of which is to ensure that adequate physical protection is provided and that any safety and warning systems are functioning correctly;

(b) Assess the efficacy of engineered controls and check again after any modification is carried out;

(c) Ensure that a written assignment of responsibilities to different levels of management is made, together with the corresponding organizational arrangements;

(d) Ensure that all workers receive appropriate refresher training at regular intervals;

(e) Ensure, when work is done jointly by a number of workers, that all the workers understand their separate and joint responsibilities for controlling the exposure of others as well as themselves to radiation and radioactive substances, and that they are adequately supervised;

(f) Ensure, with respect to each type of workplace and job, that copies of operating instructions relating to any controls adopted for that workplace and job are made easily accessible to workers, that they are available in the languages necessary to ensure comprehension by all users in the facility (through the use of pictograms where appropriate) and that they are kept in good order and legible;

(g) Make periodic appraisals of the programmes for operational radiation protection with the aim of detecting deficiencies and unnecessary redundancies that should be remedied — the interval between each appraisal should be determined on the basis of the operations, the magnitude of the routine doses, the risk of exposure and other operational parameters;

(h) Keep under review the results of the appraisals referred to in (g) above to detect trends and to determine any appropriate actions to be taken;
(i) Keep under review jobs and workplaces with the intention of keeping doses as low as reasonably achievable, economic and social factors being taken into account;
(j) Encourage workers to find ways of reducing doses;
(k) Ensure that the workers undergo the appropriate health surveillance;
(l) Provide the regulatory body, at the intervals it requires and on the timescales it specifies, with:

    (i) summaries of the records of workers' radiation exposure,
    (ii) records of measurements of concentrations of radioactive substances,
    (iii) other records as required by the regulatory body.

I.6. The employer should designate a person with the authority immediately to stop work practices that are found to be radiologically unsafe.

RESPONSIBILITIES OF WORKERS

I.7. The BSS (Ref. [2], para. I.10) state:

"Workers shall:

(a) follow any applicable rules and procedures for protection and safety specified by the employer…;
(b) use properly the monitoring devices and the protective equipment and clothing provided;
(c) co-operate with the employer… with respect to protection and safety and the operation of radiological health surveillance and dose assessment programmes;
(d) provide to the employer… such information on their past and current work as is relevant to ensure effective and comprehensive protection and safety for themselves and others;
(e) abstain from any wilful action that could put themselves or others in situations that contravene the requirements of the Standards; and
(f) accept such information, instruction and training concerning protection and safety as will enable them to conduct their work in accordance with the requirements of the Standards."

I.8. Workers have general responsibilities with respect to radiation protection. To fulfil the requirements stated in para. I.7, workers should:

(a) Refrain, unless duly authorized, from interfering with, removing, altering or displacing any safety device or other equipment (e.g. ventilation equipment) provided for the protection of themselves or others, or any method or process adopted for the control of exposure to radiation and radioactive substances, and take all reasonable precautions to prevent damage to such equipment and to keep it in good condition;
(b) Follow practices and procedures intended to suppress the generation and release of dust, to control levels and doses of radiation and to avoid accidental or unscheduled releases of radioactive substances from the facility or within it;
(c) Report any suspected accidental intake of radioactive substances;
(d) Act in compliance with all posted notices or warning signs;
(e) Adopt good personal hygiene practices such as washing before eating, wearing clean work clothes and showering at the close of work;
(f) Wash hands thoroughly before smoking in areas where smoking is allowed, if any;
(g) Contribute as required to bioassay monitoring for internal contamination;
(h) For female workers, inform their employers of pregnancy or if they are breast feeding.

I.9. Workers should consider radiation protection an integral part of a general occupational health and safety programme in which they have certain obligations and responsibilities for their own protection and that of others.

I.10. Workers should have a duty in accordance with their training and instructions to report immediately to their supervisor any situation arising from work and which they cannot properly deal with themselves that they believe could present a risk to their health and safety or to those of other persons.

I.11. In accordance with national laws and regulations, workers, through their representatives where appropriate, should have the right to remove themselves from any danger arising from their work if they have reasonable grounds for believing that there may be a serious radiological risk to their health and safety. In such circumstances, workers should inform their supervisors immediately.

Appendix II

DOSE COEFFICIENTS FOR RADIONUCLIDES OF DIFFERENT LUNG ABSORPTION TYPES

II.1. The absorption rates for inhaled radionuclides of the different lung absorption types can be expressed as approximate biological half-lives and corresponding fractions of material deposited in each region of the respiratory tract that reach body fluids. Deposition of inhaled particulates is calculated for each region of the respiratory tract, with account taken of both inhalation and exhalation. Calculations are made as a function of particle size, breathing parameters and/or workload, and the deposition is assumed to be independent of chemical form. Inhalation dose coefficients for individual radionuclides are given in Table II-III (Schedule II) of the BSS [2] for an activity median aerodynamic diameter (AMAD) of 5 µm, which is now considered to represent the most appropriate default particle size distribution for aerosols in the workplace [16].

II.2. When the fractions of the components of the fast, moderate or slow (F, M or S) lung absorption types are known for a specific material, a combined dose coefficient may be calculated as:

$$h = f_F h_F + f_M h_M + f_S h_S$$

where f_F, f_M and f_S are the fractions of fast, moderate and slow components, respectively, and h_F, h_M and h_S are the corresponding dose coefficients.

II.3. The dose per unit intake of uranium concentrate (yellow cake), calculated for an AMAD of 5 µm, varies by an order of magnitude between F and S lung absorption types. The compositions of uranium concentrates depend strongly on the specific extraction and post-extraction conditions. In particular, the use of high calcining temperatures results in an increase in the fraction of uranium compounds that dissolve relatively slowly in the lung (Type S).

II.4. The overall dose coefficients for chemically separated uranium and thorium concentrates (denoted by H_{CU} and H_{CTh}, respectively, in para. 3.12) are the averages of the dose coefficients for the individual component nuclides (as listed in the BSS), weighted according to nuclide activity concentration. Chemically separated uranium concentrate can be assumed to contain a mixture of ^{238}U and ^{234}U at equal activity concentrations and ^{235}U at an activity concentration corresponding to its natural abundance (i.e. a $^{235}U/^{238}U$ activity

TABLE II.I. INHALATION DOSE COEFFICIENTS FOR CHEMICALLY SEPARATED URANIUM AND THORIUM (AMAD = 5 μm)

Type of concentrate	Dose coefficient (Sv/Bq)		
	F	M	S
Uranium (^{238}U, ^{234}U and ^{235}U)	6.1×10^{-7}	1.8×10^{-6}	6.2×10^{-6}
Thorium (^{232}Th and ^{228}Th)	—	2.6×10^{-5}	2.2×10^{-5}

ratio of 0.046). Chemically separated thorium concentrates can be assumed to contain a mixture of ^{232}Th and ^{228}Th at equal activity concentrations. The overall dose coefficients calculated on the basis of these assumptions are shown in Table II.I for lung absorption types F, M and S and an AMAD of 5 μm. Thorium concentrates produced only by physical separation can be assumed to contain the full ^{232}Th decay chain and may be assessed in the same way as thorium ore dust (see the definition of the term H_{ODTh} in para. 3.12).

II.5. Where little or no information is available on the likely dissolution behaviour of inhaled uranium concentrates in the lung, techniques relating to the in vitro dissolution rate may be used to determine the dissolution characteristics of uranium concentrate collected in the workplace. Such procedures may then be used to estimate the fractions of F, M and S lung absorption types present in the uranium concentrate and to calculate an appropriate dose coefficient.

II.6. Similar techniques may be used to determine dose coefficients for inhaled radionuclides of mixed lung absorption types F, M and S present in uranium ore dusts and thorium ore dusts.

Appendix III

GENERAL GUIDANCE ON THE RADIATION PROTECTION PROGRAMME

SCOPE AND STRUCTURE

III.1. The Safety Guide on Occupational Radiation Protection (Ref. [7], paras 5.10 and 5.11) states[6]:

"The [radiation protection programme (RPP)] covers the main elements contributing to protection and safety, and is therefore a key factor for the development of a safety culture, 'to encourage a questioning and learning attitude to protection and safety and to discourage complacency' (Ref. [2], para. 2.28). Development of a safety culture depends on management commitment.

"Whatever the situation, the basic structure of the RPP should document, with an appropriate level of detail:

(a) The assignment of responsibilities for occupational radiation protection and safety to different management levels, including corresponding organizational arrangements and, if applicable (for example, in the case of itinerant workers), the allocation of the respective responsibilities between employers and the registrant or licensee;
(b) The designation of controlled or supervised areas;
(c) The local rules for workers to follow and the supervision of work;
(d) The arrangements for monitoring workers and the workplace, including the acquisition and maintenance of radiation protection instruments;
(e) The system for recording and reporting all the relevant information related to the control of exposures, the decisions regarding measures for occupational radiation protection and safety, and the monitoring of individuals;
(f) The education and training programme on the nature of the hazards, protection and safety;

[6] In the quotations in this Appendix from the Safety Guide on Occupational Radiation Protection [7], Ref. [2], the BSS (Safety Series No. 115), is the same as that listed as Ref. [2] in the present Safety Guide.

(g) The methods for periodically reviewing and auditing the performance of the RPP;
(h) The plans to be implemented in the event of intervention…;
(i) The health surveillance programme…;
(j) The requirements for the assurance of quality and process improvement…".

III.2. In general policy the fact should be acknowledged that the principles of radiation protection may be developed further in the future and the importance of the optimization of protection and safety should be stressed.

ASSIGNMENT OF RESPONSIBILITIES

III.3. The Safety Guide on Occupational Radiation Protection (Ref. [7], paras 5.12–5.15) states:

"To fulfil their responsibility regarding the establishment and the implementation of technical and organizational measures needed to ensure protection and safety, licensees and registrants [i.e. employers] 'may appoint other people to carry out actions and tasks related to these responsibilities, but they shall retain the responsibility for the actions and tasks themselves. Registrants and licensees shall specifically identify the individuals responsible for ensuring compliance with the Standards' (Ref. [2], para. 2.15). The responsibility for the implementation of the RPP within an organization should thus be allocated by management to staff as appropriate. The responsibilities of each hierarchical level, from the top management to the workers, regarding each aspect of the RPP should be clearly delineated and documented in written policy statements to ensure that all are aware of them. Radiation Protection Officers should be appointed, when required by the regulatory [body], to oversee the application of the regulatory requirements.

"The organizational structures should reflect the assignment of responsibilities, and the commitment of the organization to protection and safety. The management structure should facilitate co-operation between the various individuals involved. The RPP should be designed in such a way that the relevant information is provided to the individuals in charge of the various aspects of the work.

"In order to co-ordinate decision making concerning the choice of protection measures, it may be appropriate, depending on the size of the organization, to create a specific committee with representatives of those departments concerned with occupational exposure. The main role of this committee would be to advise senior management on the RPP. Its members should therefore include management staff from the relevant departments and workers with field experience. The functions of the committee should be to delineate the main objectives of the RPP in general, and operational radiation protection in particular, to validate the protection goals, to make proposals regarding the choice of protection measures and to give recommendations to management regarding the resources, methods and tools to be assigned to the fulfilment of the RPP.

"Paragraph 2.31 of the BSS (Ref. [2]) states that 'Qualified experts shall be identified and made available for providing advice on the observance of the Standards'. In particular, qualified experts in radiation protection should be identified and made available to provide advice on a range of issues, including optimization of protection and safety."

Radiation protection officer

III.4. The radiation protection officer should be suitably qualified and experienced. This may be by certification by appropriate qualification boards or societies, professional licences, academic qualifications or experience. Regulatory bodies may give advice on what can be considered suitably qualified and experienced. The radiation protection officer should implement the RPP, and in particular should:

(a) Advise management on all matters relating to radiation protection, including workplace monitoring, individual monitoring, protective equipment and administrative procedures;
(b) Identify the main sources of radiation and radioactive substances in the working environment;
(c) Direct the routine programmes for workplace monitoring and individual monitoring as well as any special monitoring programmes;
(d) Conduct programmes for dust sampling and control[7];
(e) Direct the calibration programme for all dosimeters and instruments used for workplace monitoring and individual monitoring;
(f) Participate in training programmes for workers and develop or review for approval any training material relating to radiation protection;
(g) Ensure that appropriate dose assessments are made;

[7] In operations in the mining and processing of raw materials, programmes for dust sampling and control should be conducted in conjunction with the ventilation officer, where appointed as a separate person, and may become the responsibility of the ventilation officer.

(h) Ensure that dose records are properly kept and that summaries are sent periodically to the management and to the workers (through their representatives where appropriate);
(i) Review dose records for any unusual or anomalous results, investigate such results, and provide written reports and make appropriate recommendations on them;
(j) Participate in investigations of unusual or accidental exposures and doses above the reference level, and take part in the compilation of reports to management on such investigations;
(k) Advise the occupational physician, as appropriate, on conditions in the working environment;
(l) Ensure that respiratory protection, where required, is used in accordance with recommended procedures (see Appendix V);
(m) Regularly perform assessments of the RPP and provide the management with reports on the assessments;
(n) Direct the aspects of any environmental monitoring programme that relate to radiological protection;
(o) Identify the scenarios for potential exposure and emergency conditions, and develop an appropriate emergency response plan and ensure its efficacy if actuated.

Accountability for radioactive sources

III.5. Appendix IV of the BSS (Ref. [2], para. IV.17) states:

"Registrants and licensees [i.e. employers] shall maintain an accountability system that includes records of:

(a) the location and description of each source for which they are responsible; and
(b) the activity and form of each radioactive substance for which they are responsible."

The Safety Guide on Occupational Radiation Protection (Ref. [7], para. 5.16) states that "In addition, consideration [should] be given to keeping records on any special instructions for each radioactive substance held and details of the disposal of any source.

CLASSIFICATION OF AREAS

III.6. In order to control occupational radiation exposure more effectively and consistently, workplaces should be formally designated as either 'controlled areas' or 'supervised areas' as defined in paras III.8 and III.10.

III.7. The distinction between controlled areas and supervised areas should be made on the basis of operational experience and judgement, and could be made by considering factors such as the potential for variability of external dose rates and internal doses, and the potential for the spread of contamination.

Controlled areas

III.8. Appendix I of the BSS (Ref. [2], paras I.21–I.23) states:

"Registrants and licensees [i.e. employers] shall designate as a controlled area any area in which specific protective measures or safety provisions are or could be required for:

(a) controlling normal exposures or preventing the spread of contamination during normal working conditions; and
(b) preventing or limiting the extent of potential exposures.

"In determining the boundaries of any controlled area, registrants and licensees shall take account of the magnitudes of the expected normal exposures, the likelihood and magnitude of potential exposures, and the nature and extent of the required protection and safety procedures.

"Registrants and licensees shall:

(a) delineate controlled areas by physical means or, where this is not reasonably practicable, by some other suitable means;

....

(c) display a warning symbol… and appropriate instructions at access points and other appropriate locations within controlled areas;
(d) establish occupational protection and safety measures, including local rules and procedures that are appropriate for controlled areas;
(e) restrict access to controlled areas by means of administrative procedures… and by physical barriers,… the degree of restriction being

commensurate with the magnitude and likelihood of the expected exposures;

(f) provide, as appropriate, at entrances to controlled areas:

   (i) protective clothing and equipment;
   (ii) monitoring equipment; and
   (iii) suitable storage for personal clothing;

(g) provide, as appropriate, at exits from controlled areas:

   (i) equipment for monitoring for contamination of skin and clothing;
   (ii) equipment for monitoring for contamination of any object or substance being removed from the area;
   (iii) washing or showering facilities; and
   (iv) suitable storage for contaminated protective clothing and equipment; and

(h) periodically review conditions to determine the possible need to revise the protection measures or safety provisions, or the boundaries of controlled areas."

III.9. Access to controlled areas should be restricted to ensure that workers enter only those working places to which they have been allocated. In this way, management can control workers' normal exposures and, where appropriate, doses can be assigned on the basis of workplace monitoring.

Supervised areas

III.10. Appendix I of the BSS (Ref. [2], paras I.24 and I.25) states:

"Registrants and licensees [i.e. employers] shall designate as a supervised area any area not already designated as a controlled area but where exposure conditions need to be kept under review even though specific protection measures and safety provisions are not normally needed.

"Registrants and licensees [i.e. employers] shall, taking into account the nature and extent of radiation hazards in the supervised areas:

(a) delineate the supervised areas by appropriate means;
(b) display approved signs at appropriate access points to supervised areas; and

(c) periodically review the conditions to determine any need for protective measures and safety provisions or changes to the boundaries of supervised areas."

LOCAL OPERATING INSTRUCTIONS

III.11. Paragraph I.26 (Appendix I) of the BSS [2] states:

"Employers… shall, in consultation with workers, through their representatives if appropriate:

(a) establish in writing such local rules and procedures as are necessary to ensure adequate levels of protection and safety for workers and other persons;
(b) include in the local rules and procedures the values of any relevant investigation level or authorized level, and the procedure to be followed in the event that any such value is exceeded;
(c) make the local rules and procedures and the protective measures and safety provisions known to those workers to whom they apply and to other persons who may be affected by them;
(d) ensure that any work involving occupational exposure be adequately supervised and take all reasonable steps to ensure that the rules, procedures, protective measures and safety provisions be observed".

III.12. The local operating instructions should correspond to the design and objectives of each facility and should be designed to aid the optimization of protection and safety.

III.13. Workers should be given appropriate training to enable them to comply with the local operating instructions.

III.14. Reference levels should normally correspond to specified investigative or corrective actions to be taken when the levels are exceeded. These actions should be carried out within a stated time.

III.15. Local operating instructions may include some or all of the provisions for various components of the radiation protection programme, such as:

— monitoring of exposures and contamination;
— engineering related protective measures such as ventilation systems;

— use of protective clothing;
— personal hygiene;
— health surveillance;
— management of radioactive waste;
— environmental monitoring;
— quality control;
— training;
— development of a safety culture;
— keeping of records;
— reporting.

MONITORING AND DOSE ASSESSMENT

III.16. Paragraph 2.38 of the BSS [2] states that "Monitoring and measurements shall be conducted of the parameters necessary for verification of compliance with the requirements of the Standards". The Safety Guide on Occupational Radiation Protection (Ref. [7], para. 5.39) elaborates as follows:

"Measurements related to the assessment or control of exposure to radiation and radioactive materials are described by the general term 'monitoring'. Although measurements play a major part in any RPP, monitoring is more than simply measurement; it requires interpretation and assessment. The primary justification for measurement must therefore be found in the way in which it helps to achieve and demonstrate adequate protection, including implementation of optimization of protection."

III.17. Monitoring undertaken for the purpose of individual dose assessment is subject to the following requirements (see paras I.33–I.35 (Appendix I) of the BSS [2]):

"For any worker who is normally employed in a controlled area, or who occasionally works in a controlled area and may receive significant occupational exposure, individual monitoring shall be undertaken where appropriate, adequate and feasible. In cases where individual monitoring is inappropriate, inadequate or not feasible, the occupational exposure of the worker shall be assessed on the basis of the results of monitoring of the workplace and on information on the locations and durations of exposure of the worker.

"For any worker who is regularly employed in a supervised area or who enters a controlled area only occasionally, individual monitoring shall not be required but the occupational exposure of the worker shall be assessed…

"The nature, frequency and precision of individual monitoring shall be determined with consideration of the magnitude and possible fluctuations of exposure levels and the likelihood and magnitude of potential exposures."

III.18. With regard to internal dose assessment, paras 5.55 and 5.66 of the Safety Guide on Occupational Radiation Protection [7] state:

"Individual monitoring for internal dose assessment should be used when the internal dose may be significant. Wherever possible, the intake of radioactive material should be assessed using in vivo or in vitro measurements, or by monitoring with personal air samplers.

"In general, an individual worker's radiation exposure should be assessed from the results of individual monitoring. There are occasions, particularly in the assessment of internal doses, when this may not be feasible or practicable and reliance has to be placed on workplace monitoring."

III.19. Workplace monitoring is likely to be the simpler and cheaper option for assessing intakes, but it may be unable to provide the quality of information on exposure that is necessary where intakes could be significant or variable.

III.20. Further guidance on monitoring and measurements, including examples of situations in which individual monitoring may be inappropriate or not feasible in controlled areas, is provided in the Safety Guides on assessment of exposure [8, 9].

Dose records

III.21. The employer should keep dose records as described in paras 5.75–5.85 of the Safety Guide on Occupational Radiation Protection [7]. Paragraphs 5.90 and 5.91 of Ref. [7] state:

"In general, retention periods [of the dose records] should be specified by the regulatory [body]. In the absence of such specifications, the following are suggested:

Type of record	*Suggested retention period*
Workplace monitoring, calibration of survey instrument	5 years
Occupational exposure of worker, calibration of personal monitoring equipment	Until the worker is or would be 75 years of age and 30 years after cessation of work

“The preceding recommendations concern the minimum requirements that should be prescribed by the regulatory [body] for record retention. In addition, management may choose to retain more detailed records related to specific operations, which could, for example, be used in future implementation of optimization of protection. Such operations might include maintenance or refurbishing activities.”

III.22. Paragraphs I.47 and I.48 (Appendix I) of the BSS [2] state:

“Employers… shall:

(a) provide for access by workers to information in their own exposure records;
(b) provide for access to the exposure records by the supervisor of the health surveillance programme, [and] the [regulatory body]…;
(c) …give due care and attention to the maintenance of appropriate confidentiality of records.

“If employers… cease activities that involve occupational exposure of workers, they shall make arrangements for the retention of workers’ exposure records by the [regulatory body] or State registry… as appropriate.”

INSTRUCTION OF PERSONNEL

III.23. In addition to their normal induction training in occupational health and safety, workers who are likely to be exposed to radiation should receive instruction on the topics listed in paras III.24 and III.25, as appropriate, depending on considerations such as the radiation risk, the type of facility (e.g. a mine or a processing plant) and the operational function of the worker.

Basic health and safety in relation to radiation

III.24. Training in basic health and safety in relation to radiation may include the following:

(a) the principles of radiation protection (limits and optimization);
(b) basic quantities and units in radiation protection;
(c) the properties of and hazards associated with radioactive materials;
(d) the purpose and methods of estimating workers’ radiation doses, including the use of individual monitoring and measurements;

(e) the proper practices to eliminate, limit or control radiation doses to workers, including personal hygiene and basic techniques of dose reduction, such as shielding, distance and time;
(f) the persons to be contacted on matters of radiation health and safety;
(g) the obligations of workers under the regulations issued by the regulatory body;
(h) the health effects of radiation exposure;
(i) the meaning of warning signs.

Job related health and safety

III.25. Workers should be given training in job related health and safety, which may include the following as appropriate:

(a) potential health hazards associated with the work;
(b) safe working methods and techniques — the dos and don'ts in the facility;
(c) actions to be taken after an accidental physical contact with radioactive substances or acute intake of radionuclides;
(d) the applicable health surveillance plan, the reasons for it and the need for notification of any health problems that may affect fitness for work;
(e) the proper selection, use, care and maintenance of instruments and equipment for radiation protection and individual dosimeters;
(f) the function and purpose of engineering protective measures such as ventilation systems and dust suppression systems, and the need for the immediate reporting of any breakdown to the appropriate person;
(g) the licence or registration and the local operating instructions and their application to the operation of the facility;
(h) the means of contacting key individuals such as the radiation protection officer, the occupational physician, the representative of the regulatory body and the representative of the workers;
(i) emergency plans;
(j) the locations of first aid facilities.

III.26. Supervisors should receive additional training to enable them to fulfil their supervisory obligations, such as:

(a) more advanced training in radiation protection,
(b) training in the review of workers' exposures and doses,
(c) observation of job practices.

III.27. Paragraph I.27(d) (Appendix I) of the BSS [2] requires the employer to maintain a record of the training given to individual workers. Records should include the dates when the training was given, the types of training received, certification and refresher training schedules.

III.28. The regulatory body should from time to time evaluate and validate training programmes, training materials and methods of instruction. Training schedules and records should be made available for inspection by the regulatory body.

Appendix IV

RADIATION MONITORING TECHNIQUES

IV.1. This appendix provides a summary and update of the information on monitoring techniques given in IAEA Safety Series No. 95 on Radiation Monitoring in the Mining and Milling of Radioactive Ores [21]. Further information on radiation monitoring techniques is presented in Refs [22–24].

EXTERNAL RADIATION

IV.2. Beta radiation and gamma radiation are emitted by various radionuclides in the uranium and thorium decay chains. Beta radiation is insignificant in mines but may be important in relation to skin doses in certain operations in ore processing. Levels of gamma radiation in mines generally increase with ore grades. They are normally a few tens of microsieverts per hour at the most, but can rise to 1 mSv/h at locations close to high grade ores or close to concentrates in ore processing facilities.

IV.3. For workplace monitoring, external radiation can be measured with an ionization chamber, a Geiger counter or a scintillation detector. Since the beta doses in mining and ore processing are less significant in most areas than the gamma doses, instruments that measure only the gamma dose will be adequate in some operations.

IV.4. For individual monitoring, dosimeters that measure the gamma dose only, or gamma plus beta doses, may be used. In the mining environment, thermoluminescent dosimeters or optically stimulated dosimeters are preferable to photographic film dosimeters because they are more durable and less prone to damage.

RADON (^{222}Rn) AND ITS PROGENY

IV.5. Radon is released into the atmosphere in the mine by pressure driven flow, diffusion and percolation through the ore. Unlike ore dust — the generation of which is related to the work activities in the mine — the release of radon into the mine atmosphere takes place continuously. A frequent source of radon is water percolating through the ore body, dissolving radon gas to a considerable extent and releasing it into the mine atmosphere on entering the mine openings. Because of the short half-lives of radon progeny, there is a rapid increase in their concentrations when a source of radon is present and a rapid decay when the progeny are separated from the radon source. Thus, air samples of radon progeny that are collected on a filter typically have an effective half-life of about half an hour and should be analysed soon after collection (before the activity drops to undetectable levels).

IV.6. In mine atmospheres, the ratio of the respective activity concentrations of short lived radon progeny to radon changes rapidly with the age of the ventilating air as it flows through the mine. In relatively fresh air the ratio is low, but it approaches unity in old (stagnant) air. Most radon progeny, in the form of small positive ions or neutral atoms clustered on water or other molecules in the air, become attached to atmospheric aerosol particles of about 0.3 μm diameter and therefore, like the unattached progeny, are respirable.

Workplace monitoring of radon and its progeny

IV.7. In workplace monitoring programmes radon progeny, rather than radon itself, are the primary concern. Radon measurements may be used, however, if there is a sufficiently reliable knowledge of the equilibrium factors. Alternatively, for control purposes, measurements of radon combined with measurements of radon progeny may be useful in determining equilibrium factors and deriving information on the age of the air at particular locations.

IV.8. Workplace monitoring of radon concentrations may be conducted by using various methods, including:

(a) grab sampling using alpha scintillation cells (Lucas cells);
(b) grab sampling using pulse ionization chambers;
(c) grab sampling using the two filter method;
(d) time integrated measurements using nuclear track detectors (radon cup);
(e) time integrated measurements using thermoluminescent dosimeters;
(f) ‘continuous’ monitoring (better described as frequent grab sampling) using adaptations of the grab sampling methods listed above.

IV.9. Workplace monitoring of concentrations of radon progeny generally involves active air sampling in which a known volume of air is drawn through a filter. Alpha and/or beta activity on the filter is counted during and/or after sampling. Some methods determine gross activities, while others determine the individual radon progeny concentrations. For gross alpha counting, the detection is often done simply with a scintillator disc mounted on a photomultiplier tube and placed a short distance from the filter at atmospheric pressure. Alpha spectroscopy is used to determine the activity of individual radon progeny.

IV.10. A sampling programme for the determination of concentrations of radon progeny should ideally be based on stratified random sampling. The initial design of the sampling programme should be made on the basis of the results of a screening survey of all workplaces involving multiple measurements at each location. Particular attention should be paid to the sampling statistics to ensure that the desired level of accuracy is achieved.

IV.11. The various methods used for the determination of concentrations of radon progeny are described in paras IV.12–IV.16.

One count methods

IV.12. Two commonly used one count methods are the modified Kusnetz method and the Rolle method, which differ only in the choice of sampling and counting times. Air is drawn through a filter at a rate of 2–10 L/min for a sampling time of 5–10 min. After a waiting time of up to 90 min, the gross alpha activity is integrated (usually with a scintillation counter) over a counting time of 5–10 min.

IV.13. A more recently developed one count method employs alpha spectroscopy combined with gross beta counting using a single 'passivated implanted planar silicon' (PIPS) detector [22]. This method has been extended to a semicontinuous method involving 3 min grab samples taken at 15 min intervals. The method does not need cumbersome vacuum systems for alpha spectroscopy and therefore allows the use of lightweight portable instrumentation suitable for mine environments.

Two count methods

IV.14. By taking two uncorrelated counts of the same sample, the accuracy of one count methods can be improved and the time period reduced. Various types of two count methods are used, involving alpha or alpha plus beta counting. These include the:

(a) Hill method (gross alpha);
(b) James–Strong method (gross alpha);
(c) Shreve method (gross alpha and beta);

(d) 3R/WL method and other alpha spectroscopy methods;
(e) Markov method (gross alpha).

Three count methods

IV.15. The three count methods with three uncorrelated counts during and/or after sampling are in principle free from the uncertainty inherent in one count and two count methods, but the random error, mostly due to counting statistics, may be considerable in some of the methods. Again, both gross alpha counting (the Tsivoglou method and the modified Tsivoglou or Thomas method) and alpha spectroscopy methods may be used.

Integrating and continuous radon progeny monitors

IV.16. With advances in instrumentation and microprocessing technology, sampling and analytical techniques for the measurement of radon progeny are becoming more automated. This has led to the development of various integrating (semicontinuous) and continuous instruments that can be used to measure real time changes in concentrations of radon progeny [23]. Various instruments that perform gross alpha and beta counting, as well as alpha spectroscopy, are available commercially.

Individual monitoring of radon and its progeny

IV.17. Personal monitors may be either passive or active devices. Passive dosimeters rely on the natural diffusion of airborne radioactive contaminants to the sensitive area of the detector, whereas active dosimeters collect airborne radioactive contaminants from a known volume of air drawn through a filter by a pump.

Passive individual dosimeters

IV.18. Passive individual dosimeters usually use solid state nuclear track detectors that are exposed for a specified period and then analysed by chemical and/or electrochemical etching. The number of tracks formed on the film can be counted to assess the exposure level. Devices are available for the integrated measurement of approximate concentrations of radon or radon progeny.

Active individual dosimeters

IV.19. These devices involve the drawing of a known volume of air through a filter by a battery powered pump. Alpha particles emitted by the radon progeny deposited on the filter are recorded by means of a thermoluminescent dosimeter detector disc, a silicon solid state detector with its associated electronics or a nuclear track film. Devices incorporating nuclear track films have the capability of measuring individual radon progeny rather than just the gross alpha activity.

THORON (^{220}Rn) AND ITS PROGENY

IV.20. For workplace monitoring, the various counting methods described above for radon and its progeny can in principle be adapted for thoron and its progeny, with certain limitations. Some continuous monitoring instruments can also handle thoron and its progeny.

IV.21. For individual monitoring, an integrating device based on the principle of nuclear track film detection is capable of measuring thoron progeny and hence the exposure.

ALPHA ACTIVITY IN DUST

IV.22. Alpha activity in airborne dust generated by operations in the mining and processing of raw materials is generally monitored using air sampling techniques in which particles of dust are captured by drawing the air through a filter. Monitoring for dose assessment purposes may be conducted using personal air samplers or workplace air samplers — the choice of sampling technique should take into account the requirements of the BSS (see Appendix III, para. III.17) and local circumstances. Personal samplers consist of a small filter holder and a compact, battery powered pump. Nominal flow rates are in the range 1–3 L/min.

IV.23. Dust particles captured on an air sampling filter are analysed by measuring the activities of alpha emitting radionuclides in the ^{238}U, ^{235}U and ^{232}Th series. Gross alpha counting is widely used for routine analysis where there is direct or indirect information about the likely radionuclide composition:

— For ore dust, unless there is reason to suspect that the ore body is seriously out of equilibrium, it can generally be assumed that all the radionuclides in the relevant decay series are present in radioactive equilibrium at the time of sampling;
— The radionuclide compositions of uranium and thorium concentrates are discussed in Appendix II, para. II.4.

IV.24. Radiometric analysis of individual radionuclides in dust samples involving radiochemical separation and high sensitivity measurement techniques is more accurate than gross alpha counting and avoids having to make assumptions about the radionuclide composition of the dust. Because it is time consuming and expensive, it is unlikely to be cost effective for routine analysis of individual filters, but on a non-routine basis the filters can be retained, bulked over a longer period, and the activity determined by these more sensitive analysis techniques to obtain the integrated intake over the longer period. Measurements of individual radionuclides may also be made on an infrequent basis to characterize the radionuclide composition of dust from a particular source when departure from radioactive equilibrium is suspected, thus enabling that dust to be monitored routinely using gross alpha counting.

IV.25. During the period between sampling and measurement of ore dust, some radon or thoron will escape from the dust particles collected on the sampling filter, resulting in a depletion of radon or thoron and short lived progeny in the dust at the time of measurement. An investigation [25] has found that about 25% of ^{222}Rn and ^{220}Rn leave the ore dust particles (i.e. the retention fraction is about 75%), and retention fractions of 50% and 100% have been considered as lower and upper values for uranium ore dust and uranium–thorium ore dust [26]. In order to determine the intake of gross alpha activity, therefore, a suitable correction factor should be applied to the measured gross alpha activity to account for the loss of radon or thoron and their short lived progeny. For a radon or thoron retention fraction of 75%, a correction factor of about 1.1 would be needed. Correction factors for other radon or thoron retention fractions, and details of the calculations, are given in the Annex.

CALIBRATION OF INSTRUMENTS

IV.26. For all measurement methods, instruments should be regularly calibrated and should be traceable to recognized national standards. This may be effected either by using reference sources that have been calibrated previously against primary standards or by using reference instruments that have been calibrated previously against primary standards by a national primary laboratory or at an acknowledged reference laboratory that holds appropriate standards. For most mining and ore processing operations, the former method of calibration is likely to prove more practicable.

Appendix V

PROTECTIVE RESPIRATORY EQUIPMENT

V.1. The use of respirators is required to be carefully supervised to ensure that the expected protection is provided (see para. I.28 (Appendix I) of the BSS [2]).

V.2. Management is required to ensure that the respirators fit and are used properly (see para. I.28 (Appendix I) of the BSS [2]).

V.3. The protection factors to be used in assessing the actual intake of the worker should be specified.

V.4. The periods of use of respirators should not be so long as to discourage their proper use.

V.5. Filter respirators should have a low breathing resistance and should be efficient for the dust size concerned.

V.6. When supplied air equipment is used, the air supplied should be of respirable quality and of sufficient quantity to ensure leak free operation in the conditions of use.

V.7. Powered air respirators or helmets with face shields are preferable to other types of respirator for the comfort of the workers using them, provided that they ensure effective respiratory protection.

V.8. In choosing equipment for a particular operation, factors affecting the comfort of workers (e.g. its weight, restriction of vision and effects on temperature and mobility) should be considered as well as the protection factor.

V.9. Respirators should be cleaned and maintained regularly, and inspected at appropriate intervals by properly trained persons in suitably equipped facilities.

V.10. Protective respiratory equipment should be examined, fitted and tested as appropriate by a competent person before being issued for use and at least once every three months when in use. The results of these examinations and tests and details of any repairs should be entered in a permanent register, which should be kept for the period specified by the regulatory body.

V.11. The frequency of testing of respirators should be determined on the basis of the type of respirator, the environment in which it is used and how it is handled.

V.12. Respirators should be checked by their users before use and by the safety maintenance staff after cleaning, and should be pressure tested regularly in accordance with their use.

V.13. The programme for respiratory protection should be acceptable to the regulatory body.

Appendix VI

GENERAL GUIDANCE ON HEALTH SURVEILLANCE

RESPONSIBILITY

VI.1. Health surveillance is generally the responsibility of the occupational health services, whose functions are:

(a) To assess the health of workers.
(b) To help ensure initial and continuing compatibility between the health of workers and the conditions of their work.
(c) To establish a record which provides information that would be useful in the case of:

   (i) accidental exposure or occupational disease,
   (ii) statistical evaluation of the incidence of diseases that may relate to working conditions,
   (iii) an assessment for public health purposes of the management of radiation protection in facilities in which occupational exposure can occur,
   (iv) medical–legal inquiries.

(d) To provide an advisory and treatment service in the event of personal contamination or overexposure.

VI.2. The occupational physician should:

(a) Carry out medical examinations on workers prior to their employment, periodically when they are employed and upon the termination of their employment.
(b) Advise management periodically on the fitness of workers:

- If a worker is found to be unfit for the specific work assignment, the occupational physician should indicate whether the condition is temporary or permanent and may recommend a transfer to alternative employment.
- If any ailment could have been caused by prevailing working conditions, the occupational physician should advise the management of the need to take corrective action.

(c) Give clearance for the return of workers removed from the normal working environment on medical grounds.
(d) Maintain familiarity with the working and environmental conditions.
(e) Advise as appropriate on the arrangements for hygiene at work and the removal of radionuclides from wounds.

VI.3. The occupational physician should be responsible for case management in the event of a suspected overexposure. This should include the submission of details of the case to relevant qualified experts, the counselling of the worker and the briefing of workers' representatives if appropriate. Further technical guidance in this area is given in Ref. [20].

MEDICAL EXAMINATIONS

VI.4. One main purpose of health surveillance is to ensure that workers are fit to undertake the tasks that they may be called upon to perform in accordance with the employer's description of their job. Persons employed in areas in which they may be exposed to radiation should be screened medically for fitness before commencing such employment and at appropriate intervals while so employed.

VI.5. The Safety Guide on Occupational Radiation Protection (Ref. [7], paras 7.5 and 7.6) states:

> "Medical examinations of occupationally exposed workers should follow the general principles of occupational medicine.
>
> "It should... be rare for the radiation component of the working environment to significantly influence the decision about the fitness of a worker to undertake work with radiation..."

The medical conditions that a physician should look for include those that would affect the ability to use and wear protective clothing and equipment, the ability to hear alarms and respond to radiation hazards, and the ability to use specialized tools and equipment.

VI.6. A pre-employment medical examination should be conducted for all workers who may be occupationally exposed to radiation. A specific medical history and assessment should be made for the following purposes:

(a) To determine fitness for the specific work for which the worker is to be employed,

(b) To provide a baseline for use in the consideration of changes to specific work practices,
(c) To provide a baseline for use in assessing an occupational disease or overexposure.

VI.7. The data compiled from the medical assessments may be useful for epidemiological studies.

VI.8. On completing a medical examination, the physician should communicate his or her conclusions in writing to both the worker and the employer. These conclusions should not contain information of a medical nature, but should at least categorize the worker as:

(a) Fit for work in a specific job or trade or
(b) Fit for such work with certain restrictions (for example, no work necessitating respiratory protection) or
(c) Unfit for the work in question.

VI.9. Occupational exposure to radiation may not be the only reason for performing medical examinations periodically on workers and upon the termination of their employment. Many workers exposed to radiation will be exposed to other hazards such as noise, dust and chemicals that may call for medical examinations at periodic intervals and at the termination of their employment. For example, periodic review of pulmonary function for workers in a dusty environment may be highly desirable, and the occupational physician should consider the advisability of special investigations such as tests of pulmonary function and chest X rays. Special assessments and tests may be warranted if exposures, whether to radiation or to other hazards, exceed relevant limits.

VI.10. In a medical examination at the termination of employment, any work related impairment should be identified and, if necessary, arrangements should be made for further periodic and follow-up examinations by the worker's physician after employment has ceased[8].

[8] ILO Convention and Recommendation on Occupational Cancer, 1974 (Recommendation 147, para. 12), states that "the competent authority should ensure that provision is made for appropriate medical examinations or biological or other tests or investigations to continue to be available to the worker after cessation of the assignment…"

VI.11. In keeping with good practice for occupational health, the occupational physician should ensure that the worker, on return from absence due to injury or illness, is fit to resume work.

VI.12. In special circumstances where workers who smoke have experienced lengthy exposure to dusts and/or radioactive gases and particulates, the occupational physician may need to consider instituting a programme of sputum cytology.

VI.13. The occupational physician should have the authority on medical grounds:

(a) To declare a worker temporarily unfit for his or her regular work,
(b) To advise the employer on reinstating such a worker in his or her normal duties,
(c) To recommend the transfer of a worker to other work.

NOTIFICATION OF AILMENTS, PREGNANCY AND OVEREXPOSURE

VI.14. Workers should be encouraged to report any significant ailment promptly to the occupational physician.

VI.15. The employer should ensure that every female worker of child bearing age is fully informed of the potential risks to the foetus associated with radiation exposure during pregnancy, and that the regulatory body's limits on foetal doses are complied with (Ref. [7], para. 2.39). The employer should advise female workers of child bearing age to inform the management of a pregnancy as soon as possible. Consideration should also be given to the risk of exposure of a baby during the breast feeding period, and in particular the potential for bodily contamination (by surface contact and by transfer to milk).

VI.16. A worker should report any suspected accidental intake of radioactive substances to his or her supervisor and to the radiation protection officer. The occupational physician should be informed when it is suspected that an accidental intake exceeds a limit specified by the regulatory body and should be advised of the outcome of any investigation to establish whether such an intake has actually occurred.

VI.17. When a worker has received a dose in excess of a reference level (see paras III.11(b) and III.14 of Appendix III), the regulatory body may require notification and investigation of the circumstances of the exposure.

MEDICAL RECORDS

VI.18. Medical records should include records of all medical assessments — pre-employment, periodic, special, post-illness and at the termination of employment — laboratory reports, sickness reports and medical history reports, but should exclude information on radiation exposures. Medical records should be confidential and should be preserved in a manner approved by the regulatory body. Medical records should be retained for at least the lifetimes of the workers concerned. However, because of the possibility of litigation, a longer period of retention of records may be advisable.

MEDICAL ADVICE TO MANAGEMENT

VI.19. Medical advice to management on the suitability and fitness of an individual worker for a specific job and specific assignments should be provided on the basis of full knowledge of the worker's state of health and the employer's requirements for the job. If private occupational physicians are employed on a part time basis, they should be fully informed of the biological effects of radiation. The employer should make available suitable facilities for medical examinations in the vicinity of the workplace, and should also provide appropriate opportunities for the examining occupational physicians to familiarize themselves with the intended work activities and working environments of the individuals being examined.

MEDICAL ADVICE TO WORKERS

VI.20. As in any doctor–patient relationship, the occupational physician should keep the worker fully informed of the reasons for particular examinations, as well as of any significant findings bearing on the worker's health and particular working environment.

VI.21. A further objective of the occupational health service may be to provide workers with specific counselling with regard to any radiological risks to which they are or might be subjected.

REFERENCES

[1] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, Radiation Protection and the Safety of Radiation Sources, Safety Series No. 120, IAEA, Vienna (1996).

[2] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Ann. ICRP **21** 1–3, Pergamon Press, Oxford and New York (1991).

[4] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Dose Coefficients for Intakes of Radionuclides by Workers, ICRP Publication 68, Ann. ICRP **24** 4, Pergamon Press, Oxford and New York (1994).

[5] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Conversion Coefficients for Use in Radiological Protection against External Radiation, ICRP Publication 74, Ann. ICRP **26** 3–4, Pergamon Press, Oxford and New York (1995).

[6] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, General Principles for the Radiation Protection of Workers, ICRP Publication 75, Ann. ICRP **27** 1, Pergamon Press, Oxford and New York (1997).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, Occupational Radiation Protection, Safety Standards Series No. RS-G-1.1, IAEA, Vienna (1999).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, Assessment of Occupational Exposure Due to External Sources of Radiation, Safety Standards Series No. RS-G-1.3, IAEA, Vienna (1999).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, Assessment of Occupational Exposure Due to Intakes of Radionuclides, Safety Standards Series No. RS-G-1.2, IAEA, Vienna (1999).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Radioactive Waste from the Mining and Milling of Ores, Safety Standards Series No. WS-G-1.2, IAEA, Vienna (2002).

[11] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Protection Against Radon-222 at Home and at Work, ICRP Publication 65, Ann. ICRP **23** 2, Pergamon Press, Oxford and New York (1994).

[12] INTERNATIONAL LABOUR OFFICE, Radiation Protection of Workers (Ionising Radiations), ILO, Geneva (1987).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety, Safety Standards Series No. GS-R-1, IAEA, Vienna (2000).

[14] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Radiation Protection of Workers in Mines, ICRP Publication 47, Ann. ICRP **16** 1, Pergamon Press, Oxford and New York (1986).

[15] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Individual Monitoring for Internal Exposure of Workers, ICRP Publication 78, Pergamon Press, Oxford and New York (1998).

[16] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Human Respiratory Tract Model for Radiological Protection, ICRP Publication 66, Ann. ICRP **24** 1–3, Pergamon Press, Oxford and New York (1994).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Indirect Methods for Assessing Intakes of Radionuclides Causing Occupational Exposure, Safety Reports Series No. 18, IAEA, Vienna (2000).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Direct Methods for Measuring Radionuclides in the Human Body, Safety Series No. 114, IAEA, Vienna (1996).

[19] INTERNATIONAL LABOUR ORGANISATION, Technical and Ethical Guidelines for Workers' Health Surveillance, Occupational Safety and Health Series No. 72, ILO, Geneva (1998).

[20] INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, WORLD HEALTH ORGANIZATION, Health Surveillance of Persons Occupationally Exposed to Ionizing Radiation: Guidance for Occupational Physicians, Safety Reports Series No. 5, IAEA, Vienna (1998).

[21] INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, WORLD HEALTH ORGANIZATION, Radiation Monitoring in the Mining and Milling of Radioactive Ores, Safety Series No. 95, IAEA, Vienna (1989).

[22] ROBERTS, D.A., "An alpha–beta spectrometer for estimation of individual radon daughters", J. Mine Ventilation Soc. South Africa, **48** 11 (1995) 272.

[23] GEORGE, A.C., "State of the art instruments for measuring radon/thoron and their progeny in dwellings: a review", Health Phys. **70** 4 (1996).

[24] NAZAROFF, W.W., NERO, A.V. (Eds), Radon and its Decay Products in Indoor Air, Wiley, New York (1988).

[25] DUPORT, P., EDWARDSON, E., "Characterization of radioactive long lived dust present in uranium mines and mills atmospheres", Occupational Radiation Safety in Mining (Proc. Conf. Toronto, 1984) (STOCKER, H., Ed.), Canadian Nuclear Association, Ottawa (1984).

[26] DUPORT, P., HORVATH, F., Practical aspects of monitoring and dosimetry of long-lived dust in uranium mines and mills — determination of the annual limit on intake for uranium and uranium/thorium ore dust, Radiat. Prot. Dosim. **26** 1/4 (1989) 43–48.

Annex

RELATIONSHIPS BETWEEN GROSS ALPHA ACTIVITY AND COMMITTED EFFECTIVE DOSE FOR THE INHALATION OF ORE DUST CONTAINING URANIUM OR THORIUM

GENERAL ASSUMPTIONS

A-1. It is assumed that:

- the ore dust inhaled by a worker is in full radioactive equilibrium;
- the ratio of ^{235}U activity to ^{238}U activity in uranium ore dust is the natural abundance ratio (0.046 to 1);
- the particle size distribution of the dust inhaled is represented by the default AMAD of 5 μm;
- the chemical form of each radionuclide in the dust inhaled is that corresponding to the slowest lung absorption class specified in Table II-V (Schedule II) of the BSS[1];
- a sample of airborne dust representative of that inhaled by a worker is collected on a filter and, after a delay of some days (during which some radon or thoron escapes), is analysed in a laboratory by gross alpha counting; the loss of radon or thoron from the dust particles on the filter is accompanied by a corresponding loss of short lived progeny of radon or thoron, due to the rapid decay of these progeny.

URANIUM ORE DUST

A-2. Table A-I shows, for the inhalation of ore dust containing 1 Bq of ^{238}U, the quantities (activities) of radionuclides inhaled and the corresponding committed effective doses. The doses are calculated using the dose coefficients listed in Table II-III (Schedule II) of the BSS. Using the values of total alpha activity and total committed effective dose calculated in Table A-I, the committed effective dose per unit intake of alpha activity is given by:

$$\frac{2.9\times10^{-5}\ \text{Sv}}{8.322\ \text{Bq}_\alpha} = 3.5\times10^{-6}\ \text{Sv/Bq}_\alpha = 0.0035\ \text{mSv/Bq}_\alpha$$

[1] International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

TABLE A-1. RADIONUCLIDE ACTIVITIES AND COMMITTED EFFECTIVE DOSE FOR THE INHALATION OF URANIUM ORE DUST

Radionuclide	Decay	Slowest lung absorption class	Dose coefficient (Sv/Bq)	Quantity inhaled (Bq)		Dose (Sv)
				Alpha	Beta	
^{238}U	Alpha	S	5.7×10^{-6}	1		5.7×10^{-6}
^{234}Th	Beta	S	5.8×10^{-9}		1	5.8×10^{-9}
$^{234}Pa^{m}$	Beta	—	—		1	—
^{234}U	Alpha	S	6.8×10^{-6}	1		6.8×10^{-6}
^{230}Th	Alpha	S	7.2×10^{-6}	1		7.2×10^{-6}
^{226}Ra	Alpha	M	2.2×10^{-6}	1		2.2×10^{-6}
^{222}Rn [a]	Alpha	—	—	1		—
^{218}Po [a]	Alpha	—	—	1		—
^{214}Pb [a]	Beta	F	4.8×10^{-9}		1	4.8×10^{-9}
^{214}Bi [a]	Beta	M	2.1×10^{-8}		1	2.1×10^{-8}
^{214}Po [a]	Alpha	—	—	1		—
^{210}Pb	Beta	F	1.1×10^{-6}		1	1.1×10^{-6}
^{210}Bi	Beta	M	6.0×10^{-8}		1	6.0×10^{-8}
^{210}Po	Alpha	M	2.2×10^{-6}	1		2.2×10^{-6}
^{235}U	Alpha	S	6.1×10^{-6}	0.046		2.8×10^{-7}
^{231}Th	Beta	S	4.0×10^{-10}		0.046	1.8×10^{-11}
^{231}Pa	Alpha	S	1.7×10^{-5}	0.046		7.8×10^{-7}
^{227}Ac	Beta	S	4.7×10^{-5}		0.046	2.2×10^{-6}
^{227}Th	Alpha	S	7.6×10^{-6}	0.046		3.5×10^{-7}
^{223}Ra	Alpha	M	5.7×10^{-6}	0.046		2.6×10^{-7}
^{219}Rn [a]	Alpha	—	—	0.046		—
^{215}Po [a]	Alpha	—	—	0.046		—
^{211}Pb [a]	Beta	F	5.6×10^{-9}		0.046	2.6×10^{-10}
^{211}Bi [a]	Alpha	—	—	0.046		—
^{207}Tl [a]	Beta	—	—		0.046	—
Total				8.322	6.184	2.9×10^{-5}

[a] ^{222}Rn, ^{219}Rn and short lived progeny.

the ALI corresponding to a 20 mSv dose limit is:

$$\frac{20\ \text{mSv}}{0.0035\ \text{mSv/Bq}_\alpha} = 5700\ \text{Bq}_\alpha$$

and the ALI corresponding to a 50 mSv dose limit is:

$$\frac{50\ \text{mSv}}{0.0035\ \text{mSv/Bq}_\alpha} = 14\,000\ \text{Bq}_\alpha$$

A-3. Table A-II shows, for the dust sample described in para. A-1, the alpha activities residing on the sampling filter for various fractions of radon retained in the dust at the time of measurement. Table A-II also illustrates how, for any given radon retention fraction, a comparison of the total alpha activity residing on the filter with that corresponding to 100% radon retention gives the correction factor that should be applied to the gross alpha measurement in order to obtain the alpha activity intake.

THORIUM ORE DUST

A-4. Table A-III shows again the situation described in para. A-2, but this time for ore dust containing 1 Bq of ^{232}Th. Using the values of total alpha activity and total committed effective dose calculated in Table A-III, the committed effective dose per unit intake of alpha activity is given by:

$$\frac{4.8\times10^{-5}\ \text{Sv}}{6\ \text{Bq}_\alpha} = 8.0\times10^{-6}\ \text{Sv/Bq}_\alpha = 0.0080\ \text{mSv/Bq}_\alpha$$

the ALI corresponding to a 20 mSv dose limit is:

$$\frac{20\ \text{mSv}}{0.0080\ \text{mSv/Bq}_\alpha} = 2500\ \text{Bq}_\alpha$$

and the ALI corresponding to a 50 mSv dose limit is:

$$\frac{50\ \text{mSv}}{0.0080\ \text{mSv/Bq}_\alpha} = 6300\ \text{Bq}_\alpha$$

A-5. Table A-IV shows, for the dust sample described in para. A-1, the alpha activities residing on the sampling filter for various fractions of thoron retained in the dust at the time of measurement, together with the relevant correction factors for determining the alpha activity intake as discussed in para. A-3.

TABLE A-II. ALPHA ACTIVITIES AND CORRECTION FACTORS FOR URANIUM ORE DUST RESIDING ON AN AIR SAMPLING FILTER

Alpha emitting radionuclide	Alpha activity residing on the filter for various retention fractions of ^{222}Rn and ^{219}Rn (Bq)			
	Realistic range			Hypothetical extreme case
	100%	75%	50%	0%
^{238}U	1	1	1	1
^{234}U	1	1	1	1
^{230}Th	1	1	1	1
^{226}Ra	1	1	1	1
^{222}Rn [a]	1	0.75	0.5	—
^{218}Po [a]	1	0.75	0.5	—
^{214}Po [a]	1	0.75	0.5	—
^{210}Po	1	1	1	1
^{235}U	0.046	0.046	0.046	0.046
^{231}Pa	0.046	0.046	0.046	0.046
^{227}Th	0.046	0.046	0.046	0.046
^{223}Ra	0.046	0.046	0.046	0.046
^{219}Rn [a]	0.046	0.0345	0.023	—
^{215}Po [a]	0.046	0.0345	0.023	—
^{211}Bi [a]	0.046	0.0345	0.023	—
Total (gross) alpha activity residing on the filter	8.322	7.5375	6.753	5.184
Correction factor for determining intake of alpha activity	1	1.10	1.23	1.61

[a] ^{222}Rn, ^{219}Rn and short lived progeny.

TABLE A-III. RADIONUCLIDE ACTIVITIES AND COMMITTED EFFECTIVE DOSE FOR THE INHALATION OF THORIUM ORE DUST

Radionuclide	Decay	Slowest lung absorption class	Dose coefficient (Sv/Bq)	Quantity inhaled (Bq)		Dose (Sv)
				Alpha	Beta	
^{232}Th	Alpha	S	1.2×10^{-5}	1		1.2×10^{-5}
^{228}Ra	Beta	M	1.7×10^{-6}		1	1.7×10^{-6}
^{228}Ac	Beta	S	1.2×10^{-8}		1	1.2×10^{-8}
^{228}Th	Alpha	S	3.2×10^{-5}	1		3.2×10^{-5}
^{224}Ra	Alpha	M	2.4×10^{-6}	1		2.4×10^{-6}
^{220}Rn [b]	Alpha	—	—	1		—
^{216}Po [b]	Alpha	—	—	1		—
^{212}Pb [b]	Beta	F	3.3×10^{-8}		1	3.3×10^{-8}
^{212}Bi [b]	64.1% beta, 35.9% alpha	M	3.9×10^{-8}	0.359	0.641	3.9×10^{-8}
^{212}Po [b]	Alpha	—	—	0.641		—
^{208}Tl [b]	Beta	—	—		0.349	—
Total				6	4	4.8×10^{-5}

[b] ^{220}Rn and short lived progeny.

TABLE A-IV. ALPHA ACTIVITIES AND CORRECTION FACTORS FOR THORIUM ORE DUST RESIDING ON AN AIR SAMPLING FILTER

Alpha emitting radionuclide	Alpha activity residing on the filter for various retention fractions of ^{220}Rn (Bq)			
	Realistic range			Hypothetical extreme case
	100%	75%	50%	0%
^{232}Th	1	1	1	1
^{228}Th	1	1	1	1
^{224}Ra	1	1	1	1
^{220}Rn [b]	1	0.75	0.5	—
^{216}Po [b]	1	0.75	0.5	—
^{212}Bi [b]	0.359	0.269	0.1795	—
^{212}Po [b]	0.641	0.481	0.3205	—
Total (gross) alpha activity residing on the filter	6	5.25	4.5	3
Correction factor for determining intake of alpha activity	1	1.14	1.33	2

[b] ^{220}Rn and short lived progeny.

GLOSSARY

absorbed dose. The fundamental dosimetric quantity D, defined as:

$$D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}$$

where $\mathrm{d}\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter in a volume element and dm is the mass of matter in the volume element.

action level. The level of dose rate or activity concentration above which remedial actions or protective actions should be carried out in chronic exposure or emergency exposure situations.

AMAD (activity median aerodynamic diameter). The value of aerodynamic diameter[1] such that 50% of the airborne activity in a specified aerosol is associated with particles smaller than the AMAD, and 50% of the activity is associated with particles larger than the AMAD.

authorization. The granting by a regulatory body or other governmental body of written permission for an operator to perform specified activities.

becquerel (Bq). Name for the SI unit of activity, equal to one transformation per second.

bioassay. Any procedure used to determine the nature, activity, location or retention of radionuclides in the body by direct (in vivo) measurement or by in vitro analysis of material excreted or otherwise removed from the body.

clearance. Removal of radioactive materials or radioactive objects within authorized practices from any further regulatory control by the regulatory body.

[1] The aerodynamic diameter of an airborne particle is the diameter that a sphere of unit density would need to have in order to have the same terminal velocity when settling in air as the particle of interest.

committed effective dose. The quantity $E(\tau)$, defined as:

$$E(\tau) = \sum_{T} w_T \cdot H_T(\tau)$$

where $H_T(\tau)$ is the committed equivalent dose to tissue T over the integration time τ and w_T is the tissue weighting factor for tissue T. When τ is not specified, it will be taken to be 50 years for adults and to age 70 years for intakes by children.

committed equivalent dose. The quantity $H_T(\tau)$, defined as:

$$H_T(\tau) = \int_{t_0}^{t_0+\tau} \dot{H}_T(t)dt$$

where t_0 is the time of intake, $\dot{H}_T(t)$ is the equivalent dose rate at time t in organ or tissue T and τ is the time elapsed after an intake of radioactive substances. When τ is not specified, it will be taken to be 50 years for adults and to age 70 years for intakes by children.

controlled area. A defined area in which specific protection measures and safety provisions are or could be required for controlling normal exposures or preventing the spread of contamination during normal working conditions, and preventing or limiting the extent of potential exposures.

dose constraint. A prospective and source related restriction on the individual dose delivered by a source, which serves as a bound in the optimization of protection and safety of the source. For occupational exposures, the dose constraint is a source related value of individual dose used to limit the range of options considered in the process of optimization.

dose limit. The value of the effective dose or the equivalent dose to individuals from controlled practices that shall not be exceeded.

effective dose. The quantity E, defined as a summation of the tissue equivalent doses, each multiplied by the appropriate tissue weighting factor:

$$E = \sum_{T} w_T \cdot H_T$$

where H_T is the equivalent dose in tissue T and w_T is the tissue weighting factor for tissue T. From the definition of equivalent dose, it follows that:

$$E = \sum_T w_T \cdot \sum_R w_R \cdot D_{T,R}$$

where w_R is the radiation weighting factor for radiation R and $D_{T,R}$ is the average absorbed dose in the organ or tissue T.

employer. A legal person with recognized responsibility, commitment and duties towards a worker in his or her employment by virtue of a mutually agreed relationship. (A self-employed person is regarded as being both an employer and a worker.)

equilibrium, radioactive. The state of a radioactive decay chain (or part thereof) where the activity of each radionuclide in the chain (or part of the chain) is the same.

equilibrium equivalent concentration. The activity concentration of radon in radioactive equilibrium with radon progeny that would have the same potential alpha energy concentration as the actual (non-equilibrium) mixture.

equilibrium factor. The ratio of the equilibrium equivalent concentration of radon to the actual radon concentration.

equivalent dose. The quantity $H_{T,R}$, defined as:

$$H_{T,R} = w_R \cdot D_{T,R}$$

where $D_{T,R}$ is the absorbed dose delivered by radiation type R averaged over a tissue or organ T and w_R is the radiation weighting factor for radiation type R. When the radiation field is composed of different radiation types with different values of w_R the equivalent dose is:

$$H_T = \sum_R w_R \cdot D_{T,R}$$

exclusion. The deliberate exclusion of a particular category of exposure from the scope of an instrument of regulatory control on the grounds that it is not considered amenable to control through the regulatory instrument in question. Such exposure is termed excluded exposure.

exemption. The determination by a regulatory body that a source or practice need not be subject to some or all aspects of regulatory control on the basis that the exposure (including potential exposure) due to the source or practice is too small to warrant the application of those aspects.

intake. 1. The act or process of taking radionuclides into the body by inhalation or ingestion or through the skin.
2. The activity of a radionuclide taken into the body in a given time period or as a result of a given event.

intervention. Any action intended to reduce or avert exposure or the likelihood of exposure to sources which are not part of a controlled practice or which are out of control as a consequence of an accident.

investigation level. The value of a quantity such as effective dose, intake, or contamination per unit area or volume at or above which an investigation should be conducted.

licence. A legal document issued by the regulatory body granting authorization to perform specified activities related to a facility or activity.

limit. The value of a quantity used in certain specified activities or circumstances that must not be exceeded.

monitoring. The measurement of dose or contamination for reasons related to the assessment or control of exposure to radiation or radioactive substances, and the interpretation of the results.

natural source. See source.

normal exposure. Exposure which is expected to occur under the normal operating conditions of a facility or activity, including possible minor mishaps that can be kept under control, i.e. during normal operation and anticipated operational occurrences.

occupational exposure. All exposures of workers incurred in the course of their work, with the exception of excluded exposures and exposures from exempt practices or exempt sources.

personal dose equivalent The dose equivalent in soft tissue below a specified point on the body at an appropriate depth d. Used in the BSS (with $d = 10$ mm) as a directly measurable proxy for effective dose in individual monitoring of external exposure.

potential exposure. Exposure that is not expected to be delivered with certainty but that may result from an accident at a source or owing to an event or sequence of events of a probabilistic nature, including equipment failures and operating errors.

practice. Any human activity that introduces additional sources of exposure or exposure pathways or extends exposure to additional people or modifies the network of exposure pathways from existing sources, so as to increase the exposure or the likelihood of exposure of people or the number of people exposed.

public exposure. Exposure incurred by members of the public from radiation sources, excluding any occupational or medical exposure and the normal local natural background radiation but including exposure from authorized sources and practices and from intervention situations.

radon. Radon-222.

registration. A form of authorization for practices of low or moderate risks whereby the legal person responsible for the practice has, as appropriate, prepared and submitted a safety assessment of the facilities and equipment to the regulatory body. The practice or use is authorized with conditions or limitations as appropriate. The requirements for safety assessment and the conditions or limitations applied to the practice should be less severe than those for licensing.

source. Anything that may cause radiation exposure — such as by emitting ionizing radiation or by releasing radioactive substances or materials — and can be treated as a single entity for protection and safety purposes.

natural source: a naturally occurring source of radiation, such as the sun and stars (sources of cosmic radiation) and rocks and soil (terrestrial sources of radiation).

supervised area. A defined area not designated as a controlled area but for which occupational exposure conditions are kept under review, even though specific protective measures and safety provisions are not normally needed.

thoron. Radon-220.

tissue weighting factor. Multiplier of the equivalent dose to an organ or tissue used for radiation protection purposes to account for the different sensitivities of different organs and tissues to the induction of stochastic effects of radiation.

worker. Any person who works, whether full time, part time or temporarily, for an employer and who has recognized rights and duties in relation to occupational radiation protection. (A self-employed person is regarded as having the duties of both an employer and a worker.)

CONTRIBUTORS TO DRAFTING AND REVIEW

(Names of institutions are those at the time of the meeting)

Ahmed, J.U.	Consultant, Bangladesh
Akhmetov, M.	National Nuclear Centre, Kazakhstan
Brummett, E.	Nuclear Regulatory Commission, United States of America
Burrows, S.A.	Nuclear Regulatory Commission, United States of America
de Beer, G.P.	Atomic Energy Commission, South Africa
Diamantstein, T.	Atomic Energy Control Board, Canada
Elo, S.	Hungarian Atomic Energy Authority, Hungary
Foster, P.	Institution of Professionals, Management and Specialists, United Kingdom
Kendall, G.M.	National Radiological Protection Board, United Kingdom
Khan, A.H.	Bhabha Atomic Research Centre, India
Lokan, K.	Australian Radiation Laboratory, Australia
Markkanen, M.	Radiation and Nuclear Safety Authority, Finland
Mason, G.C.	Australian Radiation Protection and Nuclear Safety Agency, Australia
McLaughlin, J.P.	University College Dublin, Ireland
Na, S.H.	International Atomic Energy Agency
Niu, S.	International Labour Office, Geneva
Owen, D.	British Nuclear Fuels Limited, United Kingdom
Poppitz, R.	Committee on the Use of Atomic Energy for Peaceful Purposes, Bulgaria
Sgrilli, E.	National Agency for the Protection of the Environment, Italy
Thomas, J.	National Centre of Public Health, Czech Republic
Viljoen, J.	Atomic Energy Control Board, Canada
Wymer, D.G.	Chamber of Mines, South Africa
Zettwoog, P.	Certac SA, France

BODIES FOR THE ENDORSEMENT OF SAFETY STANDARDS

An asterisk (*) denotes a corresponding member. Corresponding members receive drafts for comment and other documentation but they do not generally participate in meetings.

Commission on Safety Standards

Argentina: Oliveira, A.; *Brazil*: Caubit da Silva, A.; *Canada*: Pereira, J.K.; *France*: Gauvain, J.; Lacoste, A.-C.; *Germany*: Renneberg, W.; *India*: Sukhatme, S.P.; *Japan*: Tobioka, T.; Suda, N.; *Korea, Republic of*: Eun, S.; *Russian Federation*: Malyshev, A.B.; Vishnevskiy, Y.G.; *Spain*: Azuara, J.A.; Santoma, L.; *Sweden*: Holm, L.-E.; *Switzerland*: Schmocker, U.; *Ukraine*: Gryschenko, V.; *United Kingdom*: Hall, A.; Williams, L.G. (Chairperson); *United States of America*: Travers, W.D.; *IAEA*: Karbassioun, A. (Co-ordinator); *International Commission on Radiological Protection*: Clarke, R.H.; *OECD Nuclear Energy Agency*: Shimomura, K.

Nuclear Safety Standards Committee

Argentina: Sajaroff, P.; *Australia*: MacNab, D.; **Belarus*: Sudakou, I.; *Belgium*: Govaerts, P.; *Brazil*: Salati de Almeida, I.P.; *Bulgaria*: Gantchev, T.; *Canada*: Hawley, P.; *China*: Wang, J.; *Czech Republic*: Böhm, K.; **Egypt*: Hassib, G.; *Finland*: Reiman, L. (Chairperson); *France*: Saint Raymond, P.; *Germany*: Feige, G.; *Hungary*: Vöröss, L.; *India*: Kushwaha, H.S.; *Ireland*: Hone, C.; *Israel*: Hirshfeld, H.; *Japan*: Yamamoto, T.; *Korea, Republic of*: Lee, J.-I.; *Lithuania*: Demcenko, M.; **Mexico*: Delgado Guardado, J.L.; *Netherlands*: de Munk, P.; **Pakistan*: Hashimi, J.A.; **Peru*: Ramírez Quijada, R.; *Russian Federation*: Baklushin, R.P.; *South Africa*: Bester, P.J.; *Spain*: Mellado, I.; *Sweden*: Jende, E.; *Switzerland*: Aeberli, W.; **Thailand*: Tanipanichskul, P.; *Turkey*: Alten, S.; *United Kingdom*: Hall, A.; *United States of America*: Mayfield, M.E.; *European Commission*: Schwartz, J.-C.; *IAEA*: Bevington, L. (Co-ordinator); *International Organization for Standardization*: Nigon, J.L.; *OECD Nuclear Energy Agency*: Hrehor, M.

Radiation Safety Standards Committee

Argentina: Rojkind, R.H.A.; *Australia*: Melbourne, A.; **Belarus*: Rydlevski, L.; *Belgium*: Smeesters, P.; *Brazil*: Amaral, E.; *Canada*: Bundy K.; *China*: Yang, H.; *Cuba*: Betancourt Hernandez, A.; *Czech Republic*: Drabova, D.; *Denmark*: Ulbak, K.; **Egypt*: Hanna, M.; *Finland*: Markkanen, M.; *France*: Piechowski, J.; *Germany*: Landfermann, H.; *Hungary*: Koblinger, L.; *India*: Sharma, D.N.; *Ireland*: Colgan, T.; *Israel*: Laichter, Y.; *Italy*: Sgrilli, E.; *Japan*: Yamaguchi, J.; *Korea, Republic of*: Kim, C.W.; **Madagascar*: Andriambololona, R.; **Mexico*: Delgado Guardado, J.L.; **Netherlands*: Zuur, C.; *Norway*: Saxebol, G.; **Peru*: Medina Gironzini, E.; *Poland*: Merta, A.; *Russian Federation*: Kutkov, V.; *Slovakia*: Jurina, V.; *South Africa*: Olivier, J.H.I.; *Spain*: Amor, I.; *Sweden*: Hofvander, P.; Moberg, L.; *Switzerland*: Pfeiffer, H.J.; **Thailand*: Pongpat, P.; *Turkey*: Uslu, I.; *Ukraine*: Likhtarev, I.A.; *United Kingdom*: Robinson, I. (Chairperson); *United States of America*: Paperiello, C.; *European Commission*: Janssens, A.; *IAEA*: Boal, T. (Co-ordinator); *International Commission on Radiological Protection*: Valentin, J.; *International Labour Office*: Niu, S.; *International Organization for Standardization*: Perrin, M.; *International Radiation Protection Association*: Webb, G.; *OECD Nuclear Energy Agency*: Lazo, T.; *Pan American Health Organization*: Jimenez. P.; *United Nations Scientific Committee on the Effects of Atomic Radiation*: Gentner, N.; *World Health Organization*: Carr, Z.

Transport Safety Standards Committee

Argentina: López Vietri, J.; *Australia*: Colgan, P.; **Belarus*: Zaitsev, S.; *Belgium*: Cottens, E.; *Brazil*: Mezrahi, A.; *Bulgaria*: Bakalova, A.; *Canada*: Viglasky, T.; *China*: Pu, Y.; **Denmark*: Hannibal, L.; *Egypt*: El-Shinawy, R.M.K.; *France*: Aguilar, J.; *Germany*: Rein, H.; *Hungary*: Sáfár, J.; *India*: Nandakumar, A.N.; *Ireland*: Duffy, J.; *Israel*: Koch, J.; *Italy*: Trivelloni, S.; *Japan*: Saito, T.; *Korea, Republic of*: Kwon, S.-G.; *Netherlands*: Van Halem, H.; *Norway*: Hornkjøl, S.; **Peru*: Regalado Campaña, S.; *Romania*: Vieru, G.; *Russian Federation*: Ershov, V.N.; *South Africa*: Jutle, K.; *Spain*: Zamora Martin, F.; *Sweden*: Pettersson, B.G.; *Switzerland*: Knecht, B.; **Thailand*: Jerachanchai, S.; *Turkey*: Köksal, M.E.; *United Kingdom*: Young, C.N. (Chairperson); *United States of America*: Brach, W.E.; McGuire, R.; *European Commission*: Rossi, L.; *International Air Transport Association*: Abouchaar, J.; *IAEA*: Wangler, M.E. (Co-ordinator); *International Civil Aviation Organization*: Rooney, K.; *International Federation of Air Line Pilots' Associations*: Tisdall, A.; *International Maritime Organization*: Rahim, I.; *International Organization for*

Standardization: Malesys, P.; *United Nations Economic Commission for Europe*: Kervella, O.; *World Nuclear Transport Institute*: Lesage, M.

Waste Safety Standards Committee

Argentina: Siraky, G.; *Australia*: Williams, G.; **Belarus*: Rozdyalovskaya, L.; *Belgium*: Baekelandt, L. (Chairperson); *Brazil*: Xavier, A.; **Bulgaria*: Simeonov, G.; *Canada*: Ferch, R.; *China*: Fan, Z.; *Cuba*: Benitez, J.; **Denmark*: Øhlenschlaeger, M.; **Egypt*: Al Adham, K.; Al Sorogi, M.; *Finland*: Ruokola, E.; *France*: Averous, J.; *Germany*: von Dobschütz, P.; *Hungary*: Czoch, I.; *India*: Raj, K.; *Ireland*: Pollard, D.; *Israel*: Avraham, D.; *Italy*: Dionisi, M.; *Japan*: Irie, K.; *Korea, Republic of*: Song, W.; **Madagascar*: Andriambololona, R.; *Mexico*: Aguirre Gómez, J.; Delgado Guardado, J.; *Netherlands*: Selling, H.; **Norway*: Sorlie, A.; *Pakistan*: Hussain, M.; **Peru*: Gutierrez, M.; *Russian Federation*: Poluektov, P.P.; *Slovakia*: Konecny, L.; *South Africa*: Pather, T.; *Spain*: López de la Higuera, J.; Ruiz López, C.; *Sweden*: Wingefors, S.; *Switzerland*: Zurkinden, A.; **Thailand*: Wangcharoenroong, B.; *Turkey*: Osmanlioglu, A.; *United Kingdom*: Wilson, C.; *United States of America*: Greeves, J.; Wallo, A.; *European Commission*: Taylor, D.; *IAEA*: Hioki, K. (Co-ordinator); *International Commission on Radiological Protection*: Valentin, J.; *International Organization for Standardization*: Hutson, G.; *OECD Nuclear Energy Agency*: Riotte, H.