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Occupational Radiation Protection in the Mining and Processing of Raw Materials

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No. RS-G-1.6



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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
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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	1
	Background (1.1–1.4).....	1
	Objective (1.5–1.6).....	2
	Scope (1.7–1.10)	3
	Structure (1.11).....	4
2.	FULFILMENT OF REQUIREMENTS AND DISCHARGE OF RESPONSIBILITIES	4
	Applicability of requirements and recommendations (2.1–2.7)	4
	Notification and authorization (2.8–2.14)	8
	Application for authorization (2.15–2.25)	10
	Responsibilities (2.26–2.27)	13
	Inspection and non-compliance (2.28–2.35)	14
3.	DOSE LIMITATION	16
	Application of the principal radiation protection requirements (3.1–3.4)	16
	Dose limits (3.5–3.6)	17
	Special circumstances (3.7)	17
	Verification of compliance with dose limits (3.8–3.20)	18
4.	RADIATION PROTECTION PROGRAMME	24
	General (4.1–4.3)	24
	Qualified experts (4.4–4.11)	26
	Monitoring and dose assessment (4.12–4.35)	28
5.	ENGINEERING AND ADMINISTRATIVE PROTECTION MEASURES	34
	General (5.1–5.2)	34
	Ventilation (5.3–5.10)	34
	Dust control (5.11–5.12)	36
	Control related considerations for the processing of raw materials (5.13–5.20).....	37

Cleanup of spills (5.21–5.22)	38
Release of materials and equipment from mines and processing facilities (5.23–5.25)	38
Personal protective equipment (5.26–5.34)	39
Personal hygiene (5.35–5.38)	40
First aid (5.39–5.41)	41
Job rotation (5.42)	41
 6. HEALTH SURVEILLANCE (6.1–6.4)	 41
 APPENDIX I: RESPONSIBILITIES OF EMPLOYERS AND WORKERS	 43
APPENDIX II: DOSE COEFFICIENTS FOR RADIONUCLIDES OF DIFFERENT LUNG ABSORPTION TYPES	48
APPENDIX III: GENERAL GUIDANCE ON THE RADIATION PROTECTION PROGRAMME	50
APPENDIX IV: RADIATION MONITORING TECHNIQUES	62
APPENDIX V: PROTECTIVE RESPIRATORY EQUIPMENT	69
APPENDIX VI: GENERAL GUIDANCE ON HEALTH SURVEILLANCE	71
REFERENCES	76
ANNEX: RELATIONSHIPS BETWEEN GROSS ALPHA ACTIVITY AND COMMITTED EFFECTIVE DOSE FOR THE INHALATION OF ORE DUST CONTAINING URANIUM OR THORIUM	79
GLOSSARY	85
CONTRIBUTORS TO DRAFTING AND REVIEW	91
BODIES FOR THE ENDORSEMENT OF SAFETY STANDARDS..	93

1. INTRODUCTION

BACKGROUND

1.1. The mining and processing of uranium ore, thorium ore and other raw materials¹ 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 development². 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] state³:

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/m³, 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/m³ 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/m³ may be more appropriate than a value of 1000 Bq/m³.

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 intention⁶...

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 1.1–1.14 (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 years³⁸;
- (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 skin³⁹ 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 retro-active averaging.

³⁹ The equivalent dose limits for the skin apply to the average dose over 1 cm² 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 skin³⁹ 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:

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

where $H_p(d)$ is the personal dose equivalent from exposure to penetrating radiation during the year; $e(g)_{j, \text{ing}}$ and $e(g)_{j, \text{inh}}$ 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 energy⁵. 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]:

$$P_{\text{RnP}} = 5.56 \times 10^{-6} \times t \times F_{\text{RnP}} \times C_{\text{Rn}}$$

$$P_{\text{TnP}} = 7.57 \times 10^{-5} \times t \times F_{\text{TnP}} \times C_{\text{Tn}}$$

where

P_{RnP} , P_{TnP} are the potential alpha energy exposures to radon progeny and thoron progeny, respectively ($\text{mJ}\cdot\text{h}\cdot\text{m}^{-3}$),
 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:

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

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

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

where $H_p(d)$ 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; $P_{\text{RnP,L}}$, $P_{\text{TnP,L}}$ are the corresponding limits on exposure to radon progeny and thoron progeny, respectively; $I_{\text{ODU,L}}$, $I_{\text{ODTh,L}}$ are the corresponding ALIs for inhalation of ore dust containing uranium and thorium, respectively; and $I_{\text{CU,L}}$ and $I_{\text{CTh,L}}$ 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:

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

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: