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From Safety Series No. 46 onwards the various publications in the series are divided into four categories, as follows:

1. **IAEA Safety Standards.** Publications in this category comprise the Agency's safety standards as defined in "The Agency's Safety Standards and Measures", approved by the Agency's Board of Governors on 25 February 1976 and set forth in IAEA document INFCIRC/18/Rev. 1. They are issued under the authority of the Board of Governors, and are mandatory for the Agency's own operations and for Agency-assisted operations. Such standards comprise the Agency’s basic safety standards, the Agency’s specialized regulations and the Agency’s codes of practice. *The covers are distinguished by the wide red band on the lower half.*

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RADIATION PROTECTION OF WORKERS
IN THE MINING AND MILLING
OF RADIOACTIVE ORES

1983 Edition
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FOREWORD

This publication, containing the Code of Practice on Radiation Protection of Workers in the Mining and Milling of Radioactive Ores and a Technical Addendum, is a joint IAEA/ILO/WHO publication and is the revision of the joint ILO/IAEA publication on the same subject issued in 1968.

The provisions of this Code are consistent with the IAEA Safety Series No.9. They take into consideration the concepts and recommendations on radiation protection as given by the International Commission on Radiological Protection (ICRP) in its Publications Nos 24, 26 and 32.

The Code of Practice of the 1968 edition was prepared by a group of experts convened in 1965 jointly by the ILO and the IAEA. The Technical Addendum was prepared with the help of individual members of the joint meeting of experts in order to provide technical information considered to be helpful in the application of the control measures to which the Code of Practice referred. The present revised publication has been prepared by a joint IAEA/ILO/WHO Advisory Group of experts convened in 1978 in which NEA(OECD), ICRP and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) participated. The Advisory Group revised both the Code of Practice and the Technical Addendum. The revised draft was circulated among the participants for further comments and corrections. The second draft prepared on the basis of the comments from the participants was translated into French, Russian and Spanish, and was sent to all IAEA Member States, ILO Member States and WHO Regional Centres as well as some appropriate international organizations for comments. An inter-secretariat meeting, together with a consultant from France, reviewed and incorporated the comments into the draft in February 1981. The draft was further reviewed with the help of a consultant from Canada in September 1981. It was then critically reviewed and finalized in December 1981 by a joint IAEA/ILO/WHO group of consultants in which NEA(OECD) participated. The final compilation of the draft was the responsibility of Dr. J.U. Ahmed of the Division of Nuclear Safety, IAEA.

The Code of Practice was approved by the IAEA Board of Governors in June 1982. The ILO Governing Council approved it at its 221st session in November 1982. It is supplemented by a Technical Addendum, which does not
form a part of the Code but is intended to provide technical information which will be helpful in the implementation of the control measures referred to in this publication.

This Code of Practice sets forth the means of ensuring protection against ionizing radiation for workers engaged in mining and milling of radioactive ores: general provisions outlining the responsibilities of the employer and the worker, limits of radiation exposure, administrative organization of radiation protection, radiation surveillance, engineering and administrative protective measures and medical surveillance. It is designed to facilitate the preparation and adoption of national and local regulations and factory rules for radiation protection in mining and milling of radioactive ores.
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INTRODUCTION

The Code of Practice is advisory and intended for those responsible for radiation protection in the mining and milling of radioactive ores. The Code of Practice, together with its Technical Addendum, consists of a set of recommendations for the guidance of authorities, professional groups, employers' and workers' organizations and all those with responsibilities for radiation protection in mining and milling of radioactive ores. This Code may also be used as advisory material for the preparation of national or local regulations. For the purpose of this Code, 'mining' covers the activities involved in the development, excavation, removal and storage of ores, and 'milling' covers the activities involved in the physical concentration of the ores and in the production of concentrates by chemical processes. Although directed to uranium and thorium mining, the information on radiation protection presented in this Code will find application to a varying degree in other mines where radiation exists.

It has been shown that an excess lung cancer risk is correlated with high exposure to airborne radon daughter products. The hazard can be minimized by reducing exposure to radon daughters. This Code makes recommendations to this end and also towards controlling exposure to and thus risk from other sources of radiation in mines and mills. Special efforts are required to reduce exposure to radon daughters and other sources of radiation exposure, particularly by the use of ventilation and dust control.

It is realized that all the provisions of the Code may not be applicable as they stand in every mine or mill and that, as a result, some of the provisions would need to be modified to meet local or national conditions.

The Code deals with the control of occupational exposure to radiation and radioactivity in mining and milling. This Code does not cover surface exploration of radioactive ores (if no underground work is involved), decommissioning of mines and mills, and problems related to environmental protection. However, the Code may have limited application (exposure monitoring) in surface exploration for radioactive ores. Other highly significant non-radiation hazards to which workers may be exposed, such as silica dusts, mine cave-ins, explosions and fires, mechanical and electrical hazards, are common to mining and milling generally and are dealt with separately in other ILO codes of practice and publications on occupational safety and health (see Annex III).

Mining and milling of radioactive ores result in the production of radioactive wastes, which present a potential hazard to the public. In this connection, the regulations of the competent authorities should be applied and the reader is referred to the relevant standards published by the ICRP and the IAEA and guides published by the IAEA (see Annex III). This Code consequently does not consider requirements for protection of members of the public nor ways of limiting the public health impact of mining and milling.
This Code of Practice does not include specifications for equipment and devices used in mining and milling of radioactive ores. The techniques and methods of monitoring and various instruments used are covered in detail in the IAEA Safety Series No. 43. The transport of radioactive materials is covered only in so far as it takes place within the establishment; transport outside these areas is dealt with in the IAEA Safety Series No. 6.

1. SCOPE

1.1. The provisions of this Code apply to the mining and milling of uranium and thorium, to mines and mills extracting uranium or thorium as by-products, and to uranium and thorium underground exploration and development activities. Parts of the Code may find application in non-uranium mines and mills in which airborne radon or thoron daughters occur.

1.2. The provisions apply specifically to the occupational radiation hazards arising from such operations as excavation, removal and storage of ores, crushing, grinding, sorting, flotation and other physical concentration processes, as well as to the production of concentrates by chemical means.

2. GENERAL REQUIREMENTS AND PRINCIPLES

2.1. GENERAL DUTIES OF EMPLOYERS

Unless specifically stated otherwise, the responsibility for adopting and ensuring the implementation of the provisions of this Code is that of the employer. The following is a list of the principal responsibilities of the employer.

2.1.1. The employer is responsible for controlling the exposure of workers to radiation and radioactive materials. The employer should ensure that the radiation exposure of each worker and his intake of radioactive substances is controlled within the limits for individuals prescribed in this Code. All work, including storage and disposal, should be so conducted as to meet the requirements of this Code.

2.1.2. The employer should consider the protection of the health and safety of workers at all stages in the design and planning of a mining and milling project and, before commencing operations, should provide to the competent authority information on the likely radiation hazards and the methods to be adopted for controlling exposure to ionizing radiation and radioactive substances.
2.1.3. The employer should keep the individual and collective exposures of workers as low as reasonably achievable, economic and social factors being taken into account.

2.1.4. The employer should ensure that the necessary facilities, plant and equipment, personal protective equipment, work clothes, washing and first-aid facilities required by this Code are provided.

2.1.5. The employer should so provide, maintain and regularly inspect facilities, plant and equipment and should so organize the work as to ensure that the limits prescribed in Section 3 of this Code are not exceeded.

2.1.6. The employer should ensure, through supervision, that workers perform their work in accordance with the provisions of this Code.

2.1.7. The employer should ensure that every worker and supervisor is trained in the basic ventilation and radiation protection practices of the entire mine or mill, and is informed of the nature, source and potential adverse health effects of radioactive substances and of their control by means of maintenance of a proper ventilation system, proper personal hygiene and proper use of personal protective equipment.

2.1.8. The employer should ensure that every worker starting a new job is thoroughly instructed in his duties and responsibilities, the sources of exposure to radiation and radioactive substances associated with this job, and the controls, especially ventilation, adopted in accordance with the recommendations of this Code.

2.1.9. The employer, when work is done jointly by a number of persons, should ensure that all workers understand their several and joint responsibilities for controlling exposure to radiation and radioactive substances of others as well as themselves, and that they are adequately supervised.

2.1.10. The employer should ensure, with respect to each type of working place and job, that copies of the operating instructions relevant to the controls adopted for that working place and job are posted in prominent and accessible positions, that these notices (including pictograms) are in the languages necessary to ensure comprehension by all workers in the mine and mill, and that they are always legible.

2.1.11. The employer should ensure that all workers are re-instructed in the subjects specified in 2.1.7, 2.1.8 and 2.1.9 at regular intervals.

2.1.12. The employer, in agreement with the competent authority, should establish reference levels (investigation or intervention levels) based on the actual conditions in the mine or mill so that appropriate remedial actions can be taken if such levels are exceeded.
2.1.13. The employer should ensure that the workers receive the medical surveillance required by this Code.

2.1.14. The employer should inform workers that smoking enhances the risks associated with exposure to airborne radon and thoron daughters and should advise against smoking for this reason.

2.1.15. The employer should transfer to the competent authority each year summaries of the records of workers' radiation exposure, records of measurements of concentrations of radioactive substances and such other records and at such other frequencies as are required by the competent authority.

2.1.16. The employer, on closure of a mine or mill, should transfer to the competent authority all records relating to radiation exposure.

2.2. GENERAL DUTIES OF WORKERS

2.2.1. The worker should follow, as instructed by the employer, all rules and regulations for the control of exposure to radiation and radioactive substances in the working environment and refrain from careless or reckless practices or actions that are likely to result in unnecessary exposure of himself or of fellow workers.

2.2.2. The worker should use as instructed:

(a) devices, facilities and protective equipment provided to limit his exposure and that of his fellow workers to radiation and radioactive substances
(b) personal dosimeters and other exposure monitoring equipment provided to assess exposure to radiation and radioactive substances.

2.2.3. No worker, unless duly authorized, should interfere with, remove, alter, or displace any safety device, ventilation or other equipment furnished for his protection or the protection of others, or interfere with any method or process adopted for the control of exposure to radiation and radioactive substances. The worker should take all reasonable precautions to prevent damage to such equipment and keep it in good operating condition.

2.2.4. The worker should adopt good personal hygiene practices such as washing before eating and smoking, the regular use of clean work clothes and showering at the close of work because these practices assist in minimizing intakes of radioactive substances.

2.3. NOTIFICATION, REGISTRATION, LICENSING

The competent authority should be notified of proposals for the development, excavation, production, processing and handling of uranium and thorium
ores. If required, these operations should also be licensed by the competent authority in the light of the radiation hazards involved. Notification and licensing may not be required for handling natural radioactive materials containing less than 0.05 wt% of the elements uranium or thorium. The competent authority should require the applicant to demonstrate in advance that he is capable of conducting his proposed mining and milling activities in accordance with the national laws and regulations.

2.4. AGE LIMIT

No person under the age of 18 years should be regularly employed in uranium mines or mills.¹

2.5. PRINCIPLES FOR LIMITATION OF RADIATION EXPOSURE

2.5.1. All radiation exposures resulting from development, excavation, production, processing and handling of radioactive ores should be restricted by the system recommended by the ICRP, which comprises justification of the practice, optimization of radiation protection and dose-equivalent limits to individuals (see Annex I).

2.5.2. No person should unnecessarily expose himself or be unnecessarily exposed to ionizing radiation.

3. LIMITS FOR RADIATION EXPOSURE

3.1. DOSE-EQUIVALENT LIMITS

The dose-equivalent limits are not intended to be design or planning objectives. Values above the limits are specifically not permitted, but values below the limits are not automatically permitted. In this sense, the limits are a constraint for the optimization procedures.

As this Code of Practice deals with occupational protection, only the dose-equivalent limits for workers are presented:

(a) In order to prevent the occurrence of non-stochastic effects, a limit of 0.5 Sv (50 rem) in a year applies to all tissues except the lens of the eye; for the lens of the eye the recommended annual limit is 0.15 Sv (15 rem). These values

¹ See also IAEA Safety Series No.9.
apply irrespective of whether tissues are exposed singly or in combination with other tissues, and are intended to constrain exposures that fulfil the limitation for stochastic effects given below.

(b) For the limitation of stochastic effects, the limit on annual effective dose equivalent ($H_E$) is 50 mSv (5 rem).

### 3.2. SECONDARY AND DERIVED LIMITS

In practice, it is necessary to use secondary limits for external and internal exposures when compliance with the primary dose limits cannot be demonstrated directly.

3.2.1. In the case of external exposure, secondary limits may be expressed in terms of dose-equivalent index (deep dose-equivalent index and shallow dose-equivalent index).

3.2.2. In the case of internal exposure, secondary limits may be expressed in terms of the annual limits of intake (ALI). Internationally recommended values for the ALIs consistent with the dose-equivalent limits are given in the ICRP Publication No. 30, and in the IAEA Safety Series No. 9. An ALI value for radon daughters is given in the ICRP statement adopted at the Brighton meeting in 1980 (see Annex II) and in ICRP Publication No. 32. Internal exposure may also be controlled by the use of derived limits, such as a limit for the annual time integral of the concentration in air. Compliance with secondary or derived limits will ensure compliance with the annual dose-equivalent limits.

3.2.3. For clarity, in the following subsections many of the derived limits are given to two significant figures. Since the ICRP usually recommends that ALIs are accurate to only one significant figure, the reader is cautioned not to attach undue importance to the second figure. In cases of conflict among the different derived limits for a single parameter, the ALI should govern. Limits for exposure to radioactive dusts were calculated with an assumed particle size of 1 µm AMAD (Activity Median Aerodynamic Diameter). If the particle size is larger, the calculated limits will be conservative, but if the particle size is smaller, new limits should be calculated by the method in ICRP Publication No. 30.

(a) **Radon daughters.** In the mining and milling of uranium the control of exposure of workers to radon daughters is of utmost importance. The International Commission on Radiological Protection recommends an annual limit of intake by inhalation of $^{222}$Rn daughters of 0.02 J of inhaled potential alpha energy. This corresponds to a derived air concentration (DAC) of 8.3 µJ · m$^{-3}$ or 0.4 working level and to an annual limit of exposure (ALE) of 0.017 J · h · m$^{-3}$ (5 working level months).
(b) *Thoron daughters.* The ALI for thoron daughters in terms of inhaled potential alpha energy is 0.06 J. This corresponds to a DAC of 25 μJ · m⁻³ or 1.2 working levels and to an annual limit of exposure (ALE) of 0.05 J · h · m⁻³ (15 working level months).

(c) *Ore dust.* The derived limits for respirable uranium ore dust are based on the total alpha activity of the long-lived nuclides in the ²³⁸U decay chain, assumed to be in secular equilibrium with ²³⁸U. The limits for thorium ore dust are based on ²³²Th and ²²⁸Th in equilibrium. The internal doses and the ALIs are highly dependent upon the ICRP inhalation classes for the individual nuclides². It is probable that the nuclides in ore are class Y. On this basis, the ALI for uranium ore dust in terms of total long-lived alpha activity is 1.7 kBq and the DAC is 0.73 Bq · m⁻³; the ALI for thorium ore dust is 0.20 kBq and the DAC is 0.083 Bq · m⁻³. The corresponding ALEs are 1.5 kBq · h · m⁻³ for uranium and 0.17 kBq · h · m⁻³ for thorium. Should the orebody be seriously out of radioactive equilibrium, the ALIs should be calculated using the actual radionuclide ratios.

(d) *Uranium and thorium.* The ALIs for uranium and thorium are based on the naturally occurring mixtures of isotopes. Uranium and thorium concentrates vary widely in solubility, depending on the specific mill process. For class-Y material, the uranium ALI is 1.5 kBq and the DAC is 0.61 Bq · m⁻³; the thorium ALI is 0.20 kBq and the DAC is 0.083 Bq · m⁻³. For class-W material, the ALIs are 28 kBq for uranium and 63 Bq for thorium. If thorium is being concentrated from an ore containing both thorium and uranium, then the thorium ALI should be reduced to take account of the presence of ²³⁰Th.

For soluble uranium compounds (class D), chemical damage to the kidney is more important than radiological effects. Based on a threshold concentration of 900 μg of uranium in the kidney, the acute inhalation limit for uranium is 20 mg. For chronic exposure, a daily intake of 1 mg could result in the kidney limit being reached in approximately ten years.³

3.2.4. When *external and internal exposures* are received together, the individual dose limits will not be exceeded if the following two conditions are met:

\[
\frac{H_{I,d}}{50 \text{ (mSv)}} + \sum_{j} \frac{I_j}{\text{ALI}_j} \leq 1
\]

² ICRP Publication No. 30.

\[ \frac{H_{I,s}}{500 \text{ (mSv)}} \leq 1 \]

where \( H_{I,d} \) is the annual deep dose-equivalent index in millisieverts, \( H_{I,s} \) is the annual shallow dose-equivalent index in millisieverts, \( I \) is the annual intake of nuclide \( j \) in becquerels, and \( \text{ALI}_j \) is the annual limit of intake of nuclide \( j \) in becquerels.

In uranium mines this additivity has the effect of requiring the inhalation of radon and its daughters to be kept below their recommended limits by an amount that depends on the exposure to external radiation and ore dust. The combination formula is:

\[ \frac{H_{I,d}}{50} + \frac{I_{\text{RnD}}}{0.02} + \frac{I_{\text{TnD}}}{0.06} + \frac{I_{\text{ODU}}}{1700} + \frac{I_{\text{ODTh}}}{200} \leq 1 \]

where
- \( H_{I,d} \) = Annual deep dose-equivalent index in millisieverts
- \( I_{\text{RnD}} \) = Intake of radon daughters expressed in joules
- \( I_{\text{TnD}} \) = Intake of thoron daughters expressed in joules
- \( I_{\text{ODU}} \) = Intake of uranium ore dust expressed in becquerels of total long-lived alpha activity
- \( I_{\text{ODTh}} \) = Intake of thorium ore dust expressed in becquerels of total long-lived alpha activity.

In terms of exposure and practical units, the formula may be expressed as follows:

\[ \frac{H_{I,d}}{50} + \frac{E_{\text{RnD}}}{5} + \frac{E_{\text{TnD}}}{15} + \frac{E_{\text{ODU}}}{1500} + \frac{E_{\text{ODTh}}}{170} \leq 1 \]

where
- \( H_{I,d} \) = Annual deep dose-equivalent index in millisieverts
- \( E_{\text{RnD}} \) = Exposure to radon daughters in working level months
- \( E_{\text{TnD}} \) = Exposure to thoron daughters in working level months
- \( E_{\text{ODU}} \) = Exposure to uranium ore dust expressed in becquerel-hours per cubic metre of total long-lived alpha activity
- \( E_{\text{ODTh}} \) = Exposure to thorium ore dust expressed in becquerel-hours per cubic metre of total long-lived alpha activity.

\[ ^4 \text{ See Annex III of IAEA Safety Series No. 9.} \]
Similar additivity considerations apply in milling operations. In cases where inhalation or ingestion of concentrates or other radioactive substances occurs, the formula should be modified accordingly.

The ICRP Brighton Statement 1980 recognizes that in some mining operations it may not be possible to operate within the combined limits (see last paragraph of Annex II). The competent authority will then have to take a decision on how best to deal with these situations.

3.2.5. Overexposures. If an overexposure occurs, or is suspected to have occurred during normal operations or as a result of an accident or abnormal condition, the following procedure should be observed:

(a) The management should investigate the causes, determine the consequences and report to the competent authority
(b) When an exposure exceeds twice any of the annual limits specified in Section 3.2.3, the case should be subject to appropriate medical review
(c) The administrative arrangements to be made following an overexposure should include decisions about the need for any restriction on the future occupational exposure of the worker; he may still be allowed to continue routine work if there is no objection from the medical standpoint, due account having been taken of previous exposures, health, age and special skills as well as social and economic responsibilities
(d) All overexposures and accidental doses and intakes should be recorded and clearly distinguished from normal exposure, but they should be included in the individual exposure records.

3.2.6. Abnormal exposures. The competent authority should define those abnormal situations which must be reported.

4. ADMINISTRATIVE ORGANIZATION OF RADIATION PROTECTION

4.1. ADMINISTRATIVE CLASSIFICATION OF WORKERS

4.1.1. For practical purposes it may be convenient to consider two classes of workers: (i) those who work in conditions where the combined annual exposure might exceed 3/10 of the limit specified in Section 3.2.3 (working condition A); (ii) those who work in conditions where the combined annual exposure is unlikely to exceed 3/10 of the limit specified in Section 3.2.3 (working condition B).

4.1.2. The first group (condition A) should be subject to appropriate medical surveillance and should have their annual exposures assessed individually.
4.1.3. In practice it is likely that nearly all workers in an underground mine fall into working condition A. In such circumstances it may be administratively convenient to classify all mine workers in working condition A.

4.1.4. The second group (condition B) should be subject to appropriate medical surveillance, but individual exposures need not be assessed. However, area monitoring of radon and thoron daughters, gamma dose rates and radioactive dust concentrations should be used to verify compliance with Section 4.1.1 (ii). In some cases, determination of individual exposures may be carried out, for example, to obtain statistical data or to confirm the assessments made by indirect methods.

4.2. CLASSIFICATION OF AREAS

The classification of workers may be assisted by classifying working areas according to actual or potential exposure rates.

4.2.1. A Controlled Area is any working area where workers could receive combined annual exposures in excess of 3/10 of the limit specified in Section 3.2.3. Access to such an area should be controlled and subject to operating instructions. In Controlled Areas, both individual and area monitoring should be carried out. Underground mines should be classified as Controlled Areas since radiation exposure rates in them are highly variable.

4.2.2. Controlled Areas should be identified with warning signs posted at their entrances as well as within. Access should be restricted to those assigned to work in these areas and others authorized to have access.

4.2.3. A Supervised Area is any area where the combined annual exposures could exceed 1/10 but are not likely to exceed 3/10 of the limit specified in Section 3.2.3. For Supervised Areas, area monitoring should be carried out.

4.2.4. Supervised Areas should be identified with signs posted at their entrances. Access of workers should be subject to local operating instructions.

4.3. RADIATION PROTECTION

An effective radiation protection programme requires the services of the
- Medical Practitioner
- Radiation Protection Specialist
- Ventilation Specialist.

The employer should ensure that the services of these specialists are provided and that these specialists function in close co-operation and maintain close working
contact with persons responsible for the control of non-radiological hazards. The Radiation Protection Specialist and the Ventilation Specialist are considered to be in the employment of the employer, hence in this Code these two specialists are termed as Radiation Protection Officer and Ventilation Officer. The Medical Practitioner may or may not be in the employment roll, hence this term is used throughout the Code.

4.3.1. *Medical Practitioner.* The Medical Practitioner should be familiar with occupational medicine including radiation protection, and he should:

(a) **Carry out pre-employment, periodic and termination-of-employment medical examinations**

(b) Organize examinations of lung and kidney functions and, if necessary, consult with various other medical specialists as appropriate

(c) Advise the management periodically on the fitness of the workers; if a worker is found unfit for the specific work he has been assigned, the Medical Practitioner should indicate whether the condition is temporary or permanent; he may recommend a transfer to alternative employment not involving significant exposure to radiation, radioactive substances or harmful dust; if the ailment could be caused by existing unsatisfactory working conditions, he should advise the management of the need for correction

(d) Give clearance to a worker who has been temporarily withdrawn from work on medical grounds to be reinstated to normal work

(e) Periodically visit working places to know the working and environmental conditions.

4.3.2. *Radiation Protection Officer.* The Radiation Protection Officer should be a health physics specialist and he should:

(a) Advise the management on the radiological aspects of area monitoring and personal dosimetry, as well as on all other radiation protection matters including protective equipment and administrative procedures

(b) Identify the main sources of radiation and radioactive substances in the working environment

(c) Direct the routine radiation monitoring programme as well as special monitoring programmes

(d) Calibrate or assure the calibration of all dosimeters and instruments used for area monitoring and personal dosimetry

(e) Participate in worker training programmes, develop or approve any training material relating to radiation protection

(f) Ensure that exposure records are properly kept and copies are periodically sent to management

(g) Review exposure records in order to detect any unusual or anomalous results and investigate such results
(h) Participate in investigations of overexposures and other unusual or accidental exposures, and in writing reports of such investigations to management.

(i) Assist the Medical Practitioner by providing advice on radiation exposure conditions.

(j) Ensure that respiratory protection is used in accordance with the provisions of this Code.

4.3.3. **Ventilation Officer.** The Ventilation Officer should have training and experience in the design and operation of mine ventilation systems and he should:

(a) Advise the management on all matters relating to the ventilation and air purification systems.

(b) Ensure the proper operation of the ventilation system as designed and initiate revisions as the development of the mine requires.

(c) Ensure measurement of air flows and velocities and conformance with good ventilation practice.

(d) Ensure that properly calibrated instruments are used.

(e) Direct the dust sampling and control programmes.

(f) Participate in training programmes; develop or approve any training material relating to ventilation and dust control.

4.3.4. Many of the duties and advisory functions of the Radiation Protection Officer and the Ventilation Officer are interrelated and may in some cases be carried out by a single officer who has been assigned responsibility for both of these areas. When the responsibilities are divided between two officers, these officers must maintain a close working liaison with each other.

4.3.5. The Radiation Protection and Ventilation Officers should report directly to the senior representative of the employer at the mine or mill who has overall responsibility for the operation.

4.3.6. The above officers should be provided with adequate equipment and staff to fulfil their functions as outlined in this Code.

4.3.7. The effectiveness of the control measures being employed by the Radiation Protection and Ventilation Officers should be periodically assessed by the senior management.

4.4. **INSTRUCTION OF PERSONNEL**

All persons who may be exposed to radiation hazards should receive appropriate instruction regarding the following:

(a) Potential health hazards connected with their work.

(b) Safe working methods and techniques.
(c) Precautions to be taken to limit radiation exposure and intake of radioactive substances and the reasons for specific actions
(d) Main features of the ventilation system of the entire mine and the importance of proper operation of all components of the system
(e) Maintenance of proper auxiliary ventilation to provide a supply of fresh air to the working place
(f) Importance of full utilization of all means of dust suppression provided
(g) Importance and means of preventing recirculation of air locally in the working place and in larger areas of the entire mine
(h) Need for immediate reporting of any break-down of the ventilation system to the supervisor or the Ventilation Officer
(i) Proper use, operation and care of personal monitoring and personal protective equipment
(j) Importance of personal hygiene in limiting intake of radioactive substances
(k) Names of the Medical Practitioner, the Radiation Protection Officer and the Ventilation Officer, and names and addresses of the representative of the competent authority and of the representative of the workers
(l) Need for notification of any health problems
(m) First-aid measures.

Local radiation protection rules and procedures should be displayed at locations easily accessible to workers.

5. SURVEILLANCE

5.1. OBJECTIVES OF MONITORING

The principal objectives of radiation monitoring are to evaluate the exposures of workers and to provide data needed for adequate control. To achieve an effective control of radiation exposures, monitoring should facilitate:

- detection and evaluation of the principal sources of exposure
- evaluation of the effectiveness of control equipment
- detection of changes in operations (e.g. anomalies in the ventilation system) which result in increased concentrations of radioactive substances
- prediction of the effect of future operations on exposure to radiation and radioactive substances.

Detailed descriptions of the monitoring equipment and methods are available in the IAEA Manual on Radiological Safety in Uranium and Thorium Mines and Mills (Safety Series No. 43; see Annex III).
5.2. MONITORING OF THE WORKING ENVIRONMENT

5.2.1. Areas in which the combined annual individual exposures could exceed 1/10 of the limits specified in Section 3.2.3 should be monitored under the direction of the Radiation Protection Officer in consultation with the Ventilation Officer.

5.2.2. The monitoring results may be used to estimate personal exposures if personal dosimetry is not used. The frequency of monitoring should be such that the calculated individual exposures meet the desired degree of accuracy as required by the competent authority.

5.2.3. In addition, monitoring should be done for engineering control. The location of monitoring stations and the frequency of monitoring should provide data necessary to ensure the proper operation of the ventilation system and any devices for radiation control.

5.2.4. When monitoring shows that reference levels required in Section 2.1.12 are exceeded, corrective action should be taken.

5.3. EXTERNAL RADIATION SURVEILLANCE

5.3.1. When individual external exposures are to be determined, this should be done by the use of individual radiation detectors carried continuously on the person during working hours.

5.3.2. For the purpose of engineering control, external radiation surveys in working areas of mines and mills should be undertaken at intervals defined by the Radiation Protection Officer.

(a) Surveys should be made of each working area, giving particular attention to fixed working stations or other areas where workers may remain for a large part of the day.
(b) At working stations, readings should be taken at the working position.
(c) The locations surveyed and the exposure rates determined should be recorded.

5.4. RADON AND THORON DAUGHTER MONITORING

5.4.1. When individual exposures to radon and thoron daughters are to be determined, the use of a suitable personal radon and thoron daughter dosimeter worn by the worker during his working hours is preferable. Because of the limited availability of personal dosimeters, the commonly used method of determining
individual exposures based on the results of area monitoring and occupancy time is still in use in many countries.

5.4.2. Area monitoring for the purpose of determining individual exposures and for engineering control should be undertaken at a frequency determined by the Radiation Protection Officer in consultation with the Ventilation Officer, and approved by the competent authority. This frequency should be increased if:

- measured concentrations exceed the usual range in the individual working place
- major changes in the ventilation system, mine layout or mining method occur
- reference levels determined pursuant to Section 2.1.12 are exceeded
- effectiveness of corrective action pursuant to Section 5.2.4 is to be determined
- it is believed that an increase of radon and thoron flux into a working place has occurred.

5.5. RADIOACTIVE DUST MONITORING

5.5.1. In mines and mills where a possibility of significant inhalation or ingestion of radioactive dust exists, regular monitoring for radioactive dust should be instituted. The frequency of this monitoring should be determined, taking account of the concentration of radioactive dust and the potential for its inhalation or ingestion, and approved by the competent authority.

5.5.2. Measurements of radioactive surface contamination on structures and equipment in the final product area of the mill should be made in order to assess the effectiveness of the dust control system and of the measures to control intake by individuals.

5.6. BIO-ASSAYS

5.6.1. For workers in product drying and packaging areas and for workers involved in breaking and handling very high-grade ore, regular monitoring of uranium and thorium in urine should be instituted. The frequency of this monitoring should be approved by the competent authority.

5.6.2. Workers suspected of having an accidental high intake of radioactive dust by inhalation or ingestion should have urine analysis done within 24 hours of the suspected intake. Other appropriate bio-assay methods should be employed, if indicated by the result of the urine analysis, to evaluate the intake and the consequent dose equivalent.
5.6.3. Where the results of monitoring pursuant to Section 5.6.1 indicate a consistently high uranium or thorium concentration in urine, a measurement of thorax burden should be made with a whole-body counter.

5.7. MEDICAL SURVEILLANCE

5.7.1. All persons employed in mining and milling of radioactive ores should be medically examined before starting such work and at appropriate intervals thereafter. The pre-employment and periodic medical examinations should be adequate to provide information on the general health of the worker and to detect changes which may be related to his occupational exposure. In general, periodic examinations should be done at yearly intervals. Routine chest X-ray examination should be performed at intervals as long as reasonable and should not be duplicated for other examinations (e.g. silicosis).

5.7.2. For workers with long service or with high radiation exposure, sputum cytology tests may be desirable, if recommended by the Medical Practitioner or if requested by the individual worker.

5.7.3. The Medical Practitioner should have the authority on medical grounds to:
- declare a worker temporarily unfit for his regular work
- advise the employer on reinstating such a worker in his normal duties
- request the transfer of a worker to other work.

5.7.4. The Medical Practitioner's recommendations should be considered before a worker is temporarily removed from work involving significant exposure because of an exposure in excess of twice the limits specified in Section 3.2.3 and before he is subsequently reinstated.

5.7.5. Each individual exposed while working in the mining and milling of radioactive ores should undergo a medical examination on termination of employment in this occupation.

5.7.6. Medical examinations should be carried out at the expense of the employer.

5.8. NOTIFICATION OF AILMENTS, PREGNANCY AND OVEREXPOSURE

5.8.1. A worker should report promptly any significant ailment to the Medical Practitioner.

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5 For further information on medical surveillance see IAEA Safety Series No. 25 and IAEA Safety Series No. 43 (Chapter 8).

6 ILO Convention and Recommendation on Occupational Cancer, 1974 (Recommendation 147, para. 12), provides 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 referred to in para. 11 of this Recommendation”.

This publication is no longer valid
Please see http://www-ns.iaea.org/standards/
5.8.2. Pregnancy should also be reported to the Medical Practitioner in circumstances where women are employed.

5.8.3. A worker should report any suspected accidental intake of radioactive substances to his supervisor and to the Radiation Protection Officer. The Medical Practitioner should be informed.

5.8.4. When a worker has received an exposure in excess of the limits specified in Section 3.2.3, the competent authority and the worker should be notified. The competent authority should also be advised of the cause of the overexposure and the methods that are to be employed to avoid recurrence of such overexposures.

5.9. HEALTH AND MONITORING RECORDS

5.9.1. Records, in a form approved by the competent authority, should be kept. Such records should contain all relevant information concerning at least:
- the nature of the work involving radiation exposure, types of radiation and the periods during which the radiation exposure was received
- the results of assessment of individual exposures
- the results of medical examinations carried out in accordance with Section 5.7, with due regard to their confidential nature.

5.9.2. Records should be retained in such a form as the competent authority may require. They should be preserved during the lifetime of the person concerned, and in any case for at least 30 years after cessation of work involving exposure to ionizing radiation, or for such other period as the competent authority may specify.

5.9.3. Records should be handed over to the competent authority on the closure of a mine or mill.

6. ENGINEERING AND ADMINISTRATIVE PROTECTION MEASURES

6.1. CHOICE OF PROTECTION

Preference should always be given to engineered radiation protection built into the installation rather than to personal protective equipment. Personal protective equipment should be used as an additional but temporary measure until adequate engineered controls are installed.
6.2. DUST CONTROL METHODS IN MINES

The degree of dust control required to provide adequate protection of workers against non-radioactive dust hazards in the mining of radioactive ores is generally sufficient to reduce the airborne concentrations of radioactive ore dusts to below the levels given in Section 3.2.3. The following measures are recommended:

(a) The generation of dust from operations should be minimized by the use of appropriate mining techniques such as proper blasting patterns, use of water, etc.

(b) When dust is generated, it should be suppressed at the source. If necessary, the source should be enclosed under negative air pressure. In some cases the dusty air may require filtration before release to the environment.

(c) Fugitive dust which has not been suppressed at the source may be controlled with frequent air changes in the working area to dilute dust concentrations to acceptable levels. The exhaust air may have to be filtered through some form of dust collection before discharge to the environment.

(d) Where dust control methods do not achieve acceptable air quality, enclosed operating booths with filtered air supplies may be provided for the workers. This approach can be particularly useful for vehicles which are operating in an uncontrolled environment.

(e) Personal protection in the form of respirators may be supplied to the workers, but this is considered to be only a temporary measure until improvements in dust control can be effected.

6.3. VENTILATION IN UNDERGROUND MINES

6.3.1. The use of adequately designed and properly controlled ventilation systems is the most effective method of minimizing the exposure to airborne radioactive substances.

6.3.2. Ventilation design and mine planning should be conducted jointly, with the objective of achieving a 'one-pass' or parallel ventilation system to minimize the build-up of radon, thoron and their daughters, and to ensure good air quality. The implementation of such a system may create some operating problems, but it is desirable to ensure good conditions in the working environment. An effective ventilation system requires consideration of the following:

(a) Sufficient fresh air should be provided to each working area in order to ensure that the exposures to dust and radon and thoron daughters are minimized.

(b) Main mine ventilation and dust control systems should preferably be operated continuously, and no significant changes should be made unless authorized by the competent authority or in case of emergency. If the continuous operation of these systems is not reasonable, the competent authority could authorize intermittent operation subject to subsection (c) below.
(c) When the ventilation system has been changed, has failed or has been shut down, workers should be allowed to return to their working places only after the ventilation system has been restarted and appropriate monitoring has been done to ensure that the radon and thoron daughter concentrations have been reduced to acceptable levels.

6.4. CONTROL MEASURES IN THE TREATMENT OF ORES

6.4.1. In the design of mills and processes used in the extraction and concentration of radioactive materials, the confinement of the radioactive material should be the first consideration. The principles of dust control methods described in Section 6.2 are also applicable in mills. Radioactive material that cannot be effectively confined to the process should be controlled by adequate ventilation in order to control the release of contaminants and to minimize the exposure of personnel during operations.

6.4.2. Control considerations for ore treatment

(a) Crushing and screening plants should be designed and operated so as to keep the release of contaminants as low as reasonably achievable

(b) The concentrator should be designed so as to minimize the generation of airborne or liquid contaminants

(c) Concentrated radioactive and toxic materials should be handled as much as possible with automated equipment in enclosures where negative air pressure is maintained

(d) Good housekeeping should always be maintained; paint colours to be used for walls and furniture should contrast with the colours of products.

6.5. RADIATION PROTECTION

6.5.1. Engineered control measures such as good design, installation, maintenance, operation, administrative arrangements, and instruction of personnel should be used to the maximum extent possible before personal protective equipment for safety and protection of workers is utilized. In circumstances where control measures are not sufficient to provide safe working conditions, or in circumstances where emergency work has to be carried out, protective equipment should be provided to limit the exposure of the workers.

6.5.2. Personal protective equipment includes clothing, respirators, etc. Workers who may have to use it should be properly trained in its use, operation, maintenance and limitations.\(^7\)

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\(^7\) See Appendix A-3 of ICRP Publication No. 24.
6.5.3. Protective devices and equipment should be selected with consideration for the hazards involved. Personal protective equipment should not only provide adequate protection but should also be convenient and comfortable to use.

6.6. RESPIRATORY PROTECTION

6.6.1. When airborne contamination exceeds the relevant reference levels, appropriate respiratory protection should be worn while corrective measures are taken, in order to bring the contaminants to below the reference levels. While corrective measures are being undertaken, the area should be monitored to ensure that the workers are removed should excessive concentrations occur. Respiratory equipment should be used for emergency situations, repair and maintenance, and in special short-term situations. (See Technical Addendum, Section 5.5.)

6.6.2. The use of respirators should be carefully supervised to ensure that the expected protection will be provided. The management should ensure that the respirators fit and are used properly, and the efficiency coefficients to be used in assessing the actual intake of the worker (Section 3.2.3) should be defined. Respiratory protective equipment and its use should conform to the following principles:

(a) The periods of use of respirators should not be of such duration as to discourage their proper use
(b) When filter respirators are used, the filters should have a high extraction efficiency for particles below 5 μm AMAD and should have a low breathing resistance
(c) 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
(d) Powered air respirators or helmets with face shields are preferable for the comfort of workers if they provide effective respiratory protection
(e) In choosing equipment for a particular operation, the comfort of workers (e.g. weight, temperature, mobility) should be considered as well as the protection factor.
(f) Respirators should be cleaned regularly and inspected at appropriate intervals by properly trained individuals in suitably equipped facilities.

6.6.3. Respiratory protective 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 any repairs should be entered in a permanent register, which should be kept until disposal is authorized by the competent authority.
6.6.4. The respiratory protection programme should be approved by the competent authority.

6.7. OTHER PERSONAL PROTECTIVE EQUIPMENT

According to the risks of contamination, coveralls, head coverings, gloves, tight-closing boiler suits, impermeable footwear and impermeable aprons should be provided by the employer. Changing from work clothes to personal clothing, and vice versa, should be done in suitable locker rooms separated by a washroom, to control the spread of radioactive contamination. Persons should not leave working places where an appreciable contamination risk exists without taking a shower and changing clothes.

- Work clothing should be appropriate to the working conditions.
- All work clothing should be laundered at frequent intervals to minimize contamination. Suitable laundry facilities should be provided within the mine/mill complex.

6.8. FIXED WORKING STATIONS

Fixed working stations should not, in general, be located in return airways or in high external radiation areas. Where applicable, operator booths with a filtered air supply may be appropriate to provide the necessary protection.

6.9. PERSONAL HYGIENE

6.9.1. Washing facilities convenient to the place of work should be provided for all persons. Showers should be provided for all persons working under Conditions A and B.

6.9.2. A sufficient time should be allowed to each worker for the use of these washing facilities before the meal break and at the end of the shift.

6.9.3. No person should eat, drink, chew gum or tobacco, smoke or take snuff in working areas where concentrated radioactive materials might be ingested. Lunch rooms in these areas should be provided with adequate washing facilities and the workers should be instructed in procedures to minimize contamination. The lunch rooms should be clean and well ventilated.
6.10. FIRST AID

6.10.1. First-aid kits should be provided at appropriate working areas.

6.10.2. Special precautions should be taken in the cleaning of wounds caused in areas where concentrated radioactive substances are present and of wounds caused by contaminated equipment.

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

6.11. CLEAN-UP OF SPILLS

All spills of radioactive substances in mills should be cleaned up as soon as practical in order to minimize the spread of contamination. The area should be decontaminated by the removal of all loose material.

6.12. JOB ROTATION

In mines having areas with high levels of radiation exposure, when no practical means of control are available, job rotation may be considered in order to reduce the exposure of individual workers. Job rotation should only be used in exceptional circumstances and should not be a substitute for the development and use of appropriate radiation control methods.

Annex I

IMPLICATIONS OF THE ICRP DOSE LIMITATION SYSTEM

1. JUSTIFICATION

No practice resulting in human exposure to radiation should be authorized unless its introduction produces a positive net benefit, taking account of the resulting radiation detriment. Acceptance of a practice or the choice between practices by the competent authority will depend on many factors, only some of which are associated with radiation protection. For this reason, justification assessments are not discussed further in this Code of Practice.

2. OPTIMIZATION

A basic requirement of radiation protection is that all exposures should be kept 'as low as reasonably achievable', taking into account social and economic considerations. This require-
ment, usually called the 'optimization' of radiation protection, consists of reducing the collective dose (the sum of all individual doses resulting from practice) to a value such that further reductions are less significant than the additional efforts required to achieve such reductions. Optimization assessments, sometimes called the application of the ALARA principle, imply the use of differential cost-benefit analysis.8

3. INDIVIDUAL DOSE LIMITATION

The dose equivalent to individuals from all sources (except those specifically excluded) should not exceed the appropriate dose-equivalent limits. The dose-equivalent limits apply to exposures (or variation of natural exposures) which are the result of man's decisions, except those received as a patient in medical procedures. They do not apply, therefore, to exposures to natural radiation sources not associated with occupational activities.

Annex II

ICRP BRIGHTON STATEMENT

Parts of the "Statement and Recommendations of the International Commission on Radiological Protection from its 1980 Meeting"

The International Commission on Radiological Protection (ICRP) held its annual meeting in Brighton, England, from 17 to 26 March 1980, together with all four of its committees. In addition, representatives attended from the Commission of the European Communities, the International Atomic Energy Agency, the International Commission on Radiation Units and Measurements, the International Commission for Protection against Environmental Mutagens and Carcinogens, the International Electrotechnical Commission, the International Organization for Standardization, the International Radiation Protection Association, the OECD Nuclear Energy Agency, the United Nations Environment Programme, the United Nations Scientific Committee on the Effects of Atomic Radiation and the World Health Organization.

ANNUAL LIMITS FOR INTAKES OF RADIONUCLIDES

In ICRP Publication No. 30, the Commission is now in the process of recommending Annual Limits for Intakes (ALIs) of radionuclides by workers that replace its earlier recommendations in ICRP Publication No. 2 (1960). The system of dose limitation now used by the Commission takes account of all body tissues that are irradiated following the intake of radioactive material instead of only the critical organs as previously. The system ensures that the total risk from irradiation of any combination of organs does not exceed that from irradiation of the whole body at the recommended dose-equivalent limit. This summation of risks from individual organs can now be made on the basis of the much better knowledge of the sensitivity of each organ to radiation damage than was available 20 years ago. These

improvements have in themselves caused only small changes in the values of ALI for individual radionuclides, but might require a reduction in the limits for some mixtures of radionuclides. Much larger changes, however, have resulted from the improved knowledge of the uptake and retention of radionuclides in body tissues, and of the radioactive decay schemes of some radionuclides. As a result of this new information, a few values of ALI now recommended in Part 1 of ICRP Publication No. 30 (1979) are substantially greater, and others substantially smaller, than those that can be derived from ICRP Publication No. 2.

OCCUPATIONAL EXPOSURE TO RADON-222 AND ITS DAUGHTERS

The Commission reached a conclusion regarding the appropriate limit for occupational exposure to radon and its daughter nuclides. It took as the basis for this limit the level of risk corresponding to the present limit on effective dose-equivalent of 50 mSv in a year. There are several ways of assessing the relationship between the inhaled amount of radon and its daughters and the level of risk. The dosimetric method, used for most radioactive materials in ICRP Publication No. 30, and a similar method, slightly modified because of the special problems of the short-lived radon daughters, have both been used. Epidemiological studies have provided a third method. There is a reasonably close agreement between the results of these methods; the Commission recommends a limit which is at the low end of the dosimetric results and which is consistent with the epidemiological conclusions. These conclusions are not specific to radon because they relate to the consequences of exposure to the whole mining environment which includes some potentially hazardous non-radioactive agents. A Commission report is being prepared for publication.

The recommended annual limit for intake by inhalation, the ALI, for radon-222 daughters, in terms of inhaled potential alpha energy, is 0.02 J in a year. The corresponding derived air concentration (see ICRP Publication No. 30), expressed in the practical units previously widely used, is then 0.4 working level.

The system of dose limitation of the Commission requires the addition of exposures to external radiation and intakes of radioactive material. In the special case of exposure in uranium mines, this additivity has the effect of requiring the inhalation of radon and its daughters to be kept below the recommended limit by an amount that depends on the exposure to external radiation and ore dust. A reduction of 20% is common.

These recommendations are intended for competent authorities for general application and they may not always be appropriate for application in particular cases. The Commission is aware that some mining conditions are such that it may not be possible to operate within the combined limits recommended by the Commission on a year to year basis. The national authorities will then have to take decisions on how best to deal with these few, but difficult, situations.
BIBLIOGRAPHY

A. ILO ACTIVITIES CONCERNING MINING AND MILLING

A-1. Conventions and Recommendations

A-1.1. With special reference to radiation protection

- Convention No. 115, and Recommendation No. 114, concerning the protection of workers against ionizing radiations (1960).
- Convention No. 139, and Recommendation No. 147, concerning prevention and control of occupational hazards caused by carcinogenic substances and agents (1974).
- Convention No. 148, and Recommendation No. 156, concerning the protection of workers against occupational hazards due to air pollution, noise and vibration (1977).

Note. Compensation of diseases caused by ionizing radiations is provided for by Convention No. 42, concerning workmen’s compensation for occupational diseases (revised 1934), and by Convention No. 121, concerning benefits in the case of employment injury (1964).

A-1.2. With special reference to mines

- Convention No. 45, concerning the employment of women in underground work in mines of all kinds.
- Convention No. 123, and Recommendation No. 124, concerning the minimum age for admission to employment in underground mines (1965).
- Convention No. 124, concerning medical examination of young persons for fitness for employment in underground mines (1965).
- Recommendation No. 125, concerning conditions of employment of young persons in underground mines.

A-2. Codes of Practice and Guides

A-2.1. With special reference to radiation protection

- Code of Practice on Occupational Exposure to Airborne Substances Harmful to Health.

A-2.2. With special reference to mines


B. PUBLICATIONS OF THE ICRP


C. PUBLICATIONS OF THE IAEA
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This publication is no longer valid
Please see http://www-ns.iaea.org/standards/
INTRODUCTION

This technical addendum is the revised version of the technical addendum to the old Safety Series No.26. This revision was carried out by the same joint IAEA/ILO/WHO Advisory Group of experts which prepared the revised Code of Practice. The addendum does not form a part of the Code and it must be understood that the information it contains may need to be modified, taking account of local conditions and technical developments. The addendum is intended to provide technical information that would be helpful in the implementation of the control measures referred to in the Code of Practice\(^9\).

A.1. PLANNING OF MINING OPERATIONS

Uranium and thorium mines are considered to include any mine that produces ore containing uranium or thorium in sufficient quantities or concentrations to warrant exploitation, either for uranium or thorium alone or in conjunction with other substances which may be recovered in processing. What constitutes a ‘uranium or thorium mine’ will depend on the demand for uranium or thorium (and its current price as well as the commercial value of other minerals in the ore). Thus, ores containing only a few hundredths of one per cent of uranium or thorium may be exploited in some instances, while under different circumstances such ores would not be economical to recover.

The grade of ore is one of the many variables that will affect the extent and design of methods for controlling radiation exposure. Other variables include the thickness and extent of the orebodies; whether they occur in more or less continuous seams or irregular pockets; and the porosity of the host rock. In essence, there are no ‘typical’ uranium or thorium mines, and each operation must be considered to require individual treatment.

This discussion will not attempt to cover in detail the subject of radiation protection in uranium and thorium mines, but will indicate important factors which should be considered in devising procedures for controlling radiation exposure.

A.1.1. UNDERGROUND MINING

In the planning of a mining method for an underground mine it is essential that the mining engineers work in close and continual co-operation with the

\(^9\) For more detailed technical information, the reader is referred to IAEA Safety Series No.43.
Ventilation and Radiation Protection Officers. If this co-operation is effective, the production goals will be met while providing safe working conditions. Each mine has its individual peculiarities, and by applying sound engineering, radiation control and ventilation principles, the ultimate objective will be met.

The principles to be observed in planning a uranium or thorium mine are as follows:

(a) After the potential orebody has been delineated by surface drilling, initial exploratory development should be conducted in waste zones below or alongside of the anticipated ore zone, if these workings are to be used as fresh airways in the future mining stage.

(b) For a given mine production rate the working places should be few and as close together as practical rather than scattered over a large mine area, in order to obtain the maximum benefit from the ventilation system and to make supervision of the workers more effective.

(c) If practical, mining should proceed towards the fresh-air supply, with the air exhaust being through worked-out or abandoned areas. Whenever possible, the worked-out areas should be sealed off or kept under negative pressure in order to prevent ingress of radon and thoron into the working sections and potential contamination of the fresh-air supply.

(d) To facilitate removal of ore pillars, the coarse fraction of mill tailings may be used as fill. Uranium or thorium mill tailings may have a higher radon or thoron flux than the ore, but with a properly designed mining sequence and a suitable ventilation system the air quality in working areas should not be adversely affected. The slightly higher radon and thoron flux is compensated for by a reduced size of the openings, resulting in more efficient ventilation.

(e) The mining procedures used should minimize the amount of broken ore left in the working places because the amount of radon and thoron released to the air increases with the increase of ore surface exposed to the atmosphere.

A.1.2. OPEN PIT, SURFACE OR SOLUTION MINING

If the location, size and grade of the delineated orebody are suitable, it is possible to use an extraction method employing open pit or surface mining, or extraction of uranium or thorium by suitable solvents supplied and extracted through drill holes, with no physical mining of the ore, thereby minimizing or eliminating many of the health and safety problems involved in underground mining.
A.2. GUIDELINES ON VENTILATION CONTROL

The ventilation system in an underground uranium or thorium mine and mill should be developed on the basis of the following principles:

(a) The installation and satisfactory operation of the ventilation system should be under the supervision of the Ventilation Officer who is responsible to the senior representative of the employer at the mine or mill having the overall responsibility for the operation.

(b) Whenever possible and economically feasible, the ventilation system should be designed as a push (pressurized) system. The degree of the decrease of radon or thoron flux from the rock to the mine as a result of over-pressurization may vary because of the different rock porosity and tectonics, but the radon and thoron seepage from unventilated mined-out areas into zones of clean air is minimized.

(c) The control of radon and thoron daughters is a difficult task, and situations will arise where it becomes difficult to reduce the atmospheric concentrations of these substances to acceptable levels by dilution (serial) ventilation alone. A high-velocity air stream may dry out the mine surfaces and raise dust which, when inhaled, may lead to silicosis and create other hazards. Therefore, it is desirable to design the ventilation system in uranium and thorium mines as a ‘one-pass’ system whenever possible. By this method, fresh air is supplied to each working place, used once, and then removed by the return air system. In this way it is achieved that, even though large quantities of radon or thoron may be released to the working place, their residence time there is short, which results in low radon and thoron daughter concentrations. Such a system can be very effective in reducing exposures to radon and thoron daughters and to dust; it should be pointed out that this system needs considerable advance planning.

(d) The main ventilation of the mine or part of it should be operated continuously or, if this is not possible, before entry of personnel for a time sufficient to provide adequate protection against airborne radioactive materials. The main mine ventilation system should be turned off only when authorized by the competent authority or in case of emergency.

(e) The Ventilation Officer and the manager of the mine should be notified immediately of any accidental stoppage of the ventilation system. Action should be taken immediately to ensure the safety of the workers, either by evacuating them from the mine or by providing the necessary personal protective equipment.

(f) After suspension of activities during which the mechanical ventilation has been turned off or reduced for more than one shift, the workers should enter the mine only on authorization of the management and under the conditions specified.
Effective measures must be taken by the management on the advice of the Ventilation Officer in both the planning and operating stages to ensure that the fresh-air supply to each working area is not contaminated to an unacceptable level.

The ventilation airways for fresh air should be of such a size that the resultant air velocity has an optimum capacity of minimizing radon and thoron daughter build-up; at the same time, if the airways are used as regular travel ways, no dust hazard or undue discomfort of the workers should be caused.

Ventilation bulkheads and control doors require continued inspection and maintenance to minimize the waste or contamination of fresh air. If ventilation pressures are high or if there is considerable traffic through the ventilation doors, it may be necessary to minimize the loss of air by installing airlocks consisting of two ventilation doors placed a suitable distance apart.

As radon and thoron continuously stream into mine workings, high concentrations may develop rapidly if the ventilation systems are shut down. Therefore, it is important that the system be in operation for some time before the miners enter the underground area. A period of time sufficient to provide several air changes in the working areas is recommended. In mines with extensive workings it is wise to install the main fans in two independent units to ensure that, if one fan fails, about 60% of the normal air volume will be maintained. Provisions should be made to isolate the fans from the airflow so that the necessary repair work can be carried out.

Care should be taken to ensure that the air streaming into a uranium or thorium mine is not already contaminated with radon and thoron. This can happen when the air inlet is situated in a depression in the surface and conditions of atmospheric inversion exist. In such cases the use of an air-inlet chimney stack may be necessary.

The fresh air should be supplied as directly as practicable to each working place, preferably using airways that are outside the ore. This will minimize contamination of the fresh air with radon and thoron.

If working places are not supplied directly by the main current of fresh air, auxiliary ventilation should be provided through appropriate ducting. Supply of fresh air within ten metres of the working face is generally preferable to an extraction system which produces little air velocity at the working face. An alternative is an exhaust system supplemented by a short blowing system. The Ventilation Officer should specify the conditions under which the ventilation system is installed, placed in operation, stopped or modified.

The fan for auxiliary ventilation should be installed in a location upwind from the entrance to the area to be ventilated so as to prevent recirculation of the contaminated air leaving the working place.

In development headings under construction the ventilation system should be so chosen, installed, maintained and used as to keep the air in working places clear of contaminants as much as practicable.
Working areas which have been abandoned or where the work has ceased and in which safety or health hazards might exist should be effectively isolated by ventilation bulkheads or effectively ventilated and made safe. To control the air flow and to avoid contamination of the fresh-air supply, effective bulkheads must be installed close to the fresh-air routes to prevent contamination by radon and thoron from abandoned areas and leakage of contaminated return air. Bulkheads constructed of brick or concrete are usually capable of withstanding blasting concussion and limited ground pressure. To prevent seepage of radon and thoron, a negative pressure should be maintained on the contaminated side of the bulkheads or the bulkheads should be effectively coated with a sealant. The bulkheads should be installed and removed only under the instruction of the Ventilation Officer.

At times it may be necessary to perform work in an area remote from a fresh-air source. In such cases it is possible to use filters to remove entrained dust, radon and thoron daughters, and to use the air containing radon and thoron for a limited time until radon and thoron daughter concentrations reach unacceptable levels.

Since underground mine water may contain significant amounts of radon and thoron, the radon and thoron content should be checked whenever new water sources are encountered in the course of mining activities. The water will quickly release much of the contained radon and thoron to the atmosphere. Whenever possible, these point sources should be sealed. If this is not possible, the water with a high radon or thoron content should be confined in pipes as close as possible to its source and routed to a sump or other convenient location for pumping to the surface. Air from such a sump should be exhausted to the return air system. Water should be piped from each level and should not be allowed to fall to the bottom of the shaft, especially if the shaft conveys fresh air.

The effectiveness of the mine ventilation system should be continuously monitored by determining air flow rates and concentrations of airborne contaminants.

When monitoring indicates that radon and thoron daughter concentrations are approaching the investigation or intervention levels, the Ventilation Officer should take prompt action to provide adequate ventilation or respiratory protection, or withdraw the workers until corrective measures are effective.

Respirators may be used as a temporary measure for providing respiratory protection.

A copy of the ventilation plan, accompanied by a summary of the results of the dust and radiation surveys, should be sent to the manager of the mine monthly, as well as after each significant modification of the ventilation system, and yearly to the competent authority.
A.3. DUST CONTROL

Dust control systems in uranium or thorium mines or concentrators should be based on the principles outlined in the following subsections.

A.3.1. DUST CONTROL IN MINING

In mining, the four sources of dust are drilling, blasting, underground crushing and handling of rock. The magnitude of dust production varies according to the particular mining practices used. Methods for minimizing the health effects of these operations are discussed below.

A.3.1.1. Drilling

Drilling in general produces more dust of respirable size than other operations and precautions should be taken to minimize its dispersion to other working areas. Every effort should be made by the employer to inform workers of the reasons for following standard practices and the potential health hazards from dispersed dust.

The amount of airborne dust may be minimized by: use of drilling bits and machines in good condition; use of adequate water pressure; ensuring that the water is at all times turned on before the air is turned on at the drilling place; keeping the working place wet to reduce dust dispersal.

An adequate amount of water with no compressed air should be delivered to the face of the drilling bit to ensure that the rock cuttings are carried out of the drill hole without dispersing dust into the atmosphere.

If special conditions require dry drilling, an effective dry dust ejector and filter or scrubber should be used at all times with the drill.

A.3.1.2. Blasting

Whenever possible, blasting should be performed at the end of a shift. After blasting, sufficient time should be allowed so that the dust can settle or can be removed from working places by the mine ventilation system. Before a blast is ignited, the surrounding area should be thoroughly wetted to minimize dust dispersal. The use of water curtains in conjunction with blasting is desirable to reduce the amount of airborne dust.

The drilling patterns and the quantity and type of explosive used for rock fragmentation should be optimized in order to minimize generation of small particles that may become airborne.
A.3.1.3. Underground crushing of rock

Underground crushers are sometimes used to facilitate further handling of broken rock via shaft conveyance to the surface. Each new rock surface produced by crushing releases considerable dust. If water is insufficient to control this dust, the crusher should be enclosed as far as practical and an air exhaust installed to ensure that appreciable quantities of dust will not escape from the necessary openings in the crusher enclosure.

The air exhausted from the crusher should have the dust removed by efficient means before release, or the air should be discharged directly to the mine exhaust system.

At times it may be necessary to provide personnel in the crusher chamber with respiratory protective devices or to provide an enclosed operator’s booth with a supply of filtered air.

A.3.1.4. Handling of broken rock

Water in the form of jets, sprays or atomizers should be liberally used after every blast to thoroughly wet the rock faces surrounding the blast and the freshly broken rock before it is loaded. Continuous or frequent re-wetting may be required during loading to ensure that the rock remains wet; at each handling point it should be wetted again. Wetting agents or hygroscopic materials may be found beneficial, but before they are used, it should be determined that they are not toxic to personnel and do not adversely affect the metallurgical process.

The number of transfer points for broken rock should be minimized as far as practicable and, when feasible, at each such point the loading, transfer and discharge should be done within an enclosure from which the air is exhausted directly to the return airway or scrubbed before release. Without careful planning and control, ore and waste passes can be points of serious air contamination.

Transport equipment should be built, installed and used in such a manner as to minimize spills. Any spill should be cleaned up as soon as practical to minimize dust arising from drying spills.

Loading, dumping and transfer points should be so designed that operators are stationed on the fresh-air side, away from any dust source.

Returning conveyors should be efficiently cleaned to ensure that adhering fine rock does not become a dust hazard. The free-fall distance of broken rock should be minimized to limit the quantity of entrained dust that must be handled by the exhaust system.

A.3.2. DUST CONTROL IN CRUSHING AND SCREENING

Broken rock transferred from underground should not be dry. However, at each transfer or size separation by screening and at each further crushing step,
dust is released into the air. In addition to the points given in the section on mining, the following should be considered for dust control.

The exhaust air from dust enclosures should be cleaned with a high-efficiency scrubber or a bag filter, and the collected dust slurried. The resultant slurry should be recharged to the concentrator.

The crushing plant should be designed to facilitate cleaning floors by washing down, with the slurry going to the concentrator. Alternatively, a built-in vacuum system should be installed, with the resultant slurry going to the concentrator.

Frequent air changes (two to six per hour) should be provided in the crushing and screening plant. In cold climates, a heated make-up air system may be necessary to allow this frequency while providing comfortable conditions and preventing freezing. The capacity of the air supply system should be 10% in excess of the total exhaust capacity.

A.3.3. DUST CONTROL IN THE CONCENTRATOR

In the concentrator, most of the operations are wet and dust is much less of a problem than in the mine or the crushing and screening plant. However, toxic chemicals may be hazardous in addition to the radiological hazards as the uranium and thorium become more concentrated.

Feed to and discharge from the grinding mills may release moderate dust concentrations. Grinding being a wet process, normally little dust is released once the ore is in the mill and usually two to six air changes per hour in this area provide acceptable conditions.

Mill tanks should be covered and vented through the roof of the building. Natural draught stacks are usually adequate for covered tanks unless the tanks are agitated, in which case a powered exhaust may be necessary.

In the final stages of the milling process, i.e. during precipitation and packing, care should be taken to prevent dispersal of the product into the air. Automation of concentrate handling should be considered where practical to minimize personnel exposure. It should be noted that the chemical toxicity of uranium is significant and, therefore, good housekeeping and good personal hygiene should be practised.

Product packaging and sampling areas of the mill should be enclosed, with the air exhausted and passed through a scrubber to remove radioactive dust.

The tailings slurry, which contains the pulverized waste after the uranium or thorium has been extracted, normally still contains over 95% of the total radionuclides that were originally contained in the ore. The liquid fraction usually contains high levels of radium in solution and low levels of other radionuclides, plus chemicals and heavy metals. The solid fraction may be divided into a coarse or sand portion and slimes, the latter containing higher concentrations of radium.
A.4. RADIATION MONITORING IN URANIUM AND THORIUM MINES

Detailed descriptions of the monitoring equipment and methods are given in the IAEA Safety Series No. 43. References [1] and [2] may also be consulted. The following is a brief outline of the essential points in radiation monitoring in uranium and thorium mines.

A.4.1. PURPOSE AND SCOPE

The purposes of radiation monitoring in uranium and thorium mines are:

- to obtain records of personal radiation exposure and radionuclide intake
- to demonstrate compliance with the regulations governing radiation exposure and intake of radionuclides
- to provide information for efficient engineering control of the ventilation and radiation control systems.

In order to achieve the purposes outlined above, the following types of monitoring should be carried out:

- concentrations of radon and thoron daughters in air
- personal radon and thoron daughter exposures, utilizing integrated personal radon and thoron daughter dosimeters (if feasible and technically possible)
- concentrations of long-lived alpha-emitting radionuclides in airborne dust
- gamma dose rate
- personal gamma exposures, utilizing integrated personal gamma dosimeters
- in special circumstances, concentrations of $^{230}$Th, $^{210}$Pb and $^{210}$Po in air and external beta dose rate.

A.4.2. MONITORING OF RADON, THORON AND RADON DAUGHTERS

As radon daughters constitute the most significant radiation hazard in the majority of underground uranium mines and thoron daughters in thorium mines, it is essential that proper measurements of their concentrations in the air are made.

Thoron and thoron daughters do not constitute the most significant hazards in uranium mines. However, many operating uranium mines have thorium associated with uranium in the ore and therefore every uranium mine should be occasionally monitored for thoron and thoron daughters; if no appreciable concentrations are found, regular monitoring is not necessary. Regular thoron and thoron daughter monitoring should be carried out in thorium mines.
Air sampling should be performed (1) in the working place and designated rest area (lunch room), with the sampling location chosen to ensure that the sample is representative of the air breathed by the workers; and (2) at other appropriate places in the mine, as a means of engineering assessment of the ventilation and radiation control systems.

Air samples should be taken in such a manner that an average value for the whole working cycle is obtained (e.g. at the time of drilling, at the time of returning to work after blasting, during the removal of the broken rock, during the auxiliary follow-up work).

The frequency of air sampling should be such as to enable proper calculation of the individual exposure for each worker. The current method of calculation is to multiply radon and thoron daughter concentrations in the air by the duration of stay in the place with this concentration.

It is difficult to recommend a generally applicable monitoring frequency. As a general rule, it may be suggested that if measurements over a period of three to six months indicate that concentrations of radon daughters vary by less than ± 25%, a monitoring frequency of once to twice a month is sufficient. If the concentrations vary by more than ± 25% or if they are subject to sudden changes caused by certain operations (opening and closing of ventilation doors, closeness of ore or waste passes, etc.), a monitoring frequency of at least once a week is necessary. The reference levels should be used to prescribe a certain monitoring frequency as a result of measured concentrations. (See Appendices A.I and A.II.)

Personal radon and thoron daughter dosimeters for obtaining integrated exposures have been introduced recently [3 – 6]. If they prove reliable, their use is advisable because personal dosimetry gives the best estimate of individual exposures.

Sampling of radon and thoron is normally done by collecting air samples in evacuated chambers made of glass, metal or plastic. Increasing use is being made of similar chambers through which the sample air is passed until all the original air has been replaced, after which the chambers are sealed and evaluated as usual.

Some instrumentation is in use which, with minor adjustments, can be used to measure either radon and thoron concentrations in flasks or radon and thoron daughters collected on the usual filters. Other instrumentation simultaneously determines radon and thoron and their daughters from the same air sample. This capability may be of advantage in special circumstances such as determining the ‘age of air’ when tracing sources of air contamination. Instrumentation incorporating a digital read-out is more convenient to use than that using a rate meter.

When sampling and measurement involve the determination of several parameters, then the measurements of all parameters should be made in the given place at approximately the same time.

All instruments should be properly calibrated and used according to specifications. The results should be recorded properly.
A.4.3. MONITORING OF GAMMA RADIATION

Monitoring of personal gamma exposures of individual workers should be done with personal gamma dosimeters. Film badges may be used; however, the most suitable personal dosimeters for the harsh mine environment are thermoluminescent dosimeters (TLD). To minimize contamination and loss of such a dosimeter, the holder and its attachment should be rugged, watertight and dust-tight. Other holders such as those used in less demanding environments in other areas of the nuclear industry are unlikely to be satisfactory.

In mines with exceptionally high-grade ore, short-term exposure monitoring is necessary for an adequate dose control programme. In these mines, the worker should also wear a direct-reading dosimeter which should be read and the values recorded daily.

For the purpose of engineering control, regular gamma dose-rate monitoring should be undertaken in designated locations utilizing an appropriate gamma dose-rate meter properly calibrated.

A.4.4. MONITORING OF LONG-LIVED ALPHA EMITTERS

Monitoring of long-lived alpha emitters in the air should be carried out for each working place at least once every three months.

If the concentration of the long-lived alpha emitters is greater than 25% of the derived air concentration, it is recommended that analyses be done for $^{226}$Ra, uranium and $^{230}$Th to determine the radioactive equilibrium. If the ore is out of equilibrium, the ore dust ALI and DAC should be recalculated.

Dust samples from fixed-area samplers or from personal gravimetric samplers should be analysed quarterly for gross alpha activity or total uranium to confirm that concentrations are below the DACs.

Proper sampling instrumentation must work at two stages, with a cyclone or impactor used to separate the coarser non-respirable fraction from the respirable portion which is collected on a filter. At least half a cubic metre of air may have to be collected to obtain sufficient material for analysis. The usual analysis is for gross alpha activity per unit air volume after the radon daughters have decayed.

The exposure of individual workers to long-lived alpha emitters can be measured more accurately with personal air samplers worn on the body than by calculations based on area sampling and occupancy time. The personal sampler integrates the worker’s exposure for an entire shift or an entire work-week without encumbering normal activities. The sampler or detector is analysed after the exposure period, to yield either cumulative or average exposure, as desired.
A.5. RADIATION PROTECTION
IN URANIUM AND THORIUM MILLS

A.5.1. INTRODUCTION

The term 'uranium or thorium mill' includes any plant which processes
uranium or thorium ore to produce a physical or chemical concentrate.

In uranium or thorium mills, workers may be exposed to external beta and
gamma radiation, and also to internal contamination as a result of inhalation and
ingestion of the radioactive materials being processed [7—9]. In contrast to the
situation in mines, radon and thoron and their daughters usually represent only a
minor problem in mills, the main radiation hazard being from inhaled and ingested
uranium or thorium.

A.5.2. INTERNAL CONTAMINATION IN MILLS

The primary sources of internal contamination in uranium and thorium mills
are the crushing and grinding sections and the final-product precipitation, drying
and packaging sections. Standard techniques of dust control should be used in
areas where crushers, screens and transfer points generate dust. These techniques
include wetting the ore and the use of dust enclosures and exhaust ventilation.
In the final-product areas, it is essential to practise good housekeeping in addition
to having efficient dust enclosures, exhaust ventilation, etc. The use of protective
clothing and respirators is necessary, especially at the final packaging station.

Vacuum equipment should be used for clean-up work rather than brooms,
which raise dust into the air. The operators should wear respirators during plant
clean-up. Gloves should be used for protection against contamination of the skin
with uranium and thorium, against absorption of these materials through the skin
and against the less penetrating beta rays during drum-loading operations. Strict
personal hygiene should be enforced. Smoking and eating should be strictly
prohibited in the drying and packaging areas. A daily change of coveralls should
be provided to the workers.

Monitoring should be done with personal and area dust samplers (see
Section A.4.4). The material collected on the filter by the sampler should be
analysed for uranium and thorium or ore dust.

Samples should be taken either in the 'breathing zone' or in the 'general area'.
If dust originates from a point source, the breathing-zone concentration may be
five to ten times the general-area concentration. When taken at the proper location,
however, a general-area sample is satisfactory to determine the effectiveness of
control measures. To compute the weighted-average daily exposure of a worker, breathing-zone samples must be collected for all potentially dust-producing operations and general-area samples in all other areas which may be occupied by workers, such as lunch rooms, locker rooms and rest rooms. The most accurate way to determine the exposure of an employee during an eight-hour shift is by utilizing an individual personal air sampler to obtain the time-weighted average exposure.

The inhalation of airborne material is normally the main route of entry of radionuclides into the human body. It is difficult to assess the resulting doses because many complex parameters have to be considered. The IAEA Technical Reports Series No. 142 serves as a manual of guidance for radiation protection personnel concerned with inhalation risks relating to radiation workers.

There are no universally accepted values for the limits of skin and surface contamination by alpha emitters. For uranium and thorium, the following permissible limits are given in the IAEA Safety Series No. 43 (p.15):

- skin — 0.37 Bq • cm⁻² (10⁻³ μCi • cm⁻²),
- surface — 37 Bq • cm⁻² (10⁻³ μCi • cm⁻²).

The latter level is appropriate only in limited areas; more generally, surface contamination should not exceed 4 Bq • cm⁻² (10⁻⁴ μCi • cm⁻²).

### A.5.3. EXTERNAL RADIATION

The exposure of workers to external fields of beta and gamma radiation in uranium and thorium mills is generally comparable with that in uranium and thorium mines. However, the exposure may be significantly higher in certain locations, mainly in the final stages of precipitation, filtration, drying, concentrate packaging, sampling and storage.

The gamma radiation fields may vary from mill to mill, depending on ore grade, type, grade and age of concentrate, as well as type of process. During operation, intermediate and final products and radium may accumulate in pipes and tanks and give rise to high local radiation fields (IAEA Safety Series No. 43, Section 3.3.2). Generally, external radiation hazards assume significance mainly in the final stages of precipitation, filtration, concentrate packaging and storage. Freshly separated uranium and thorium are primarily alpha emitters, but as daughter products build up, both beta and gamma activities also build up. The beta-gamma activity reaches about 50% of equilibrium in 24 days [10]. It should be borne in mind that the incoming ore can create a significant external radiation hazard if it is of sufficiently high grade.

Exposures should be monitored utilizing personal dosimeters (see Section A.4.3). In addition, gamma dose-rate monitoring should be undertaken for engineering assessment of the performance of radiation control systems.
A.5.4. PROTECTIVE CLOTHING

Coveralls, cloth caps and cotton gloves are often supplied to workers to reduce skin contamination and to prevent the spread of radioactive materials. However, such clothing, usually referred to as work clothing, does not provide sufficient protection against toxic materials.

Rubber jackets, rubber aprons, rubber boots and rubber gloves provide a high degree of protection against toxic or corrosive materials. Such articles, usually referred to as protective clothing, are provided for workers engaged in operations requiring exposure to toxic materials and should be carefully selected to afford protection against the specific substances involved.

Work clothing should be monitored for radioactive contamination and should be laundered regularly within the facility.

A.5.5. USE OF RESPIRATORY PROTECTION

It is important to recognize that respirators are not to be considered as a substitute for good engineering control measures. Primary consideration should always be given to preventing the air in uranium or thorium mills from becoming contaminated. However, there are circumstances in which respirators are necessary in routine operations and in emergencies, for instance:

- in a new mill or in sections thereof, until effective operation of the ventilation system is established
- during drum-loading operations as an additional protection measure
- during maintenance of contaminated equipment or during failure of ventilation or dust control systems
- during handling of toxic chemicals
- during plant clean-up operations.

The selection of respiratory protection requires a thorough knowledge of all factors involved, including the concentration of contaminants, the nature of the duties to be performed by the worker, and an understanding of the design, scope and performance of the various types of respirators available. There are four broad categories of respirators: air-purifying respirators (full and half face), hose-type air-supplying respirators, self-contained breathing apparatus, and helmet-type respirators with filtered air supplied to the breathing zone through the helmet and between the face shield and the face. Only respirators approved by the competent authority should be used.

No person should be permitted to wear a respirator unless it has been properly fitted and he has been instructed in its use. The proper maintenance of the respirator is also most important. Hyatt [11] suggests that respirators used
in uranium or thorium mills should be monitored before cleaning and that those which show over 0.37 Bq \cdot \text{cm}^{-2} \left(10^{-5} \, \mu\text{Ci} \cdot \text{cm}^{-2}\right) of surface alpha activity should be segregated from the others to prevent cross-contamination during cleaning. Hyatt also suggests that the upper limit of airborne contamination for which half-face type respirators may be used should be ten times the DAC and for full-face type respirators the limit should be 100 times the DAC. Further details can be found in Ref. [11].

It should be noted that, in all uranium and thorium mills for which information is available, respirators are used in the product-packaging sections. These sections should be physically separated from the remainder of the plant and should have an independent ventilation system.

A.5.6. URINE ANALYSIS

In addition to measurements of the concentration of radionuclides in the air, all uranium and thorium mills should carry out a programme of regular urine sampling of exposed workers to note the occurrence of uranium and thorium intakes.

Urinalysis for uranium is important, as the chemical damage to the kidney is likely to be more severe than the radiation damage to body tissues from entry of transportable compounds of natural uranium into the blood. Within 24 hours of the entry of uranium into extracellular fluid, half to three-quarters of the amount is excreted in urine. Thus urinalysis provides a ready check on the occurrence of recent internal contamination, but only in individuals who do not have any appreciable pre-existing body content of uranium is it possible to relate the urinary level to body or organ content.\(^{10}\)

Urinalysis is usually limited to workers who are likely to be exposed to uranium concentrations approaching the DAC. Thus, usually only mill workers need to be considered.

The usual procedure of urinalysis is to collect a urine sample weekly, on Monday before the worker’s first shift, in order to avoid the period of rapid excretion that occurs immediately after inhalation of uranium, and to minimize sample contamination from the body and contaminated clothing. Nevertheless, scrupulous care is mandatory to ensure that the samples are free of contamination. Uranium analyses may be performed either by fluorometric or radiometric methods [12].

The excretion of 150 \(\mu\text{g}\) of uranium within 24 hours is considered to signify an intake approaching the toxicological limit at some time in the previous

\(^{10}\text{ICRP Publication No. 10, Evaluation of Radiation Doses to Body Tissues from Internal Contamination due to Occupational Exposure, Pergamon Press, Oxford (1968) 86.}\)
week. This calls for a review of control measures, air concentrations and workers' personal hygiene habits in order to preclude a recurrence of exposure. It is suggested that the sample be checked for albumin at this uranium excretion level, as an indication of possible kidney damage.

The total excretion of uranium within 24 hours can be estimated from the concentration in a single urine sample by using the standard excretion volume of 1.4 L per day as a normalizing factor. However, this is subject to the error associated with variability in excretion volume. Somewhat better reliability can be attained by analysing the sample for creatinine content and normalizing by the total daily excretion of creatinine, which is uniform in individuals eating meat regularly [13]. Urinalyses are no more than guides and should always be interpreted cautiously because of the variability of uranium and thorium elimination rates, urinary volume and other parameters.

Urinalysis for thorium should be carried out for natural thorium or $^{228}$Ra, or both, depending on the nature of the chemical operations in which the workers are engaged. A 16-hour urine sample is collected for analysis. The procedure of urinalysis for natural thorium is based on spectrophotometric measurement after extraction by thenoyl-trifluoroacetone (TTA). The investigation level is considered to be 9 μg per 24 hours, which is calculated by normalizing by the total daily excretion of creatinine.

The procedure for the measurement of $^{228}$Ra in urine involves the determination of the growth of $^{228}$Ra daughter products three days after carrier separation of radium.

A.5.7. PRODUCT PACKAGING

It is recommended that uranium and thorium concentrates (physical or chemical) should be packed in strong industrial-type containers, e.g. heavy-gauge steel drums with bolted ring closures. Containers of this type are acceptable for transport outside the mill premises according to the IAEA Regulations for the Safe Transport of Radioactive Materials (Safety Series No.6).

Since they may constitute an external radiation hazard, containers filled with uranium and thorium concentrates should be stored in an area separate from the working areas in the plant and not on the plant boundary. This is especially important when the material is stored for long periods, because of the gradual build-up of uranium and thorium daughters and the resultant increase in the gamma radiation field.

When any uranium or thorium concentrate is spilled in the storage area, adequate precautions against the spread of contamination should be taken during clean-up operations. Respirators, protective clothing, vacuum cleaning and water should be used as appropriate.
A.5.8. SURFACE CONTAMINATION

Surface contamination can be a significant problem, mainly where operations such as precipitation, filtration, weighing and packaging are carried out; these may need monitoring (IAEA Safety Series No.43, Section 3.3.3).

A.6. MEDICAL CONTROL

A.6.1. GENERAL

All persons employed in mining and milling of radioactive ores should be medically examined before commencing such work and at appropriate intervals thereafter. Medical examinations should be carried out at no expense to the worker.

A.6.2. MEDICAL EXAMINATIONS

The pre-employment and periodic medical examinations should be adequate to provide information on the general health of the worker and to detect changes which may be related to his occupational exposure.

The pre-employment examination should be a thorough examination. In general, periodic examinations should be done at yearly intervals for exposed workers. The periodic examinations should include an enquiry into the general health of the worker, with special emphasis on certain organ systems. A medical examination should also be carried out at the termination of employment. The following sections provide guidance on the medical history, the physical examination and on laboratory studies.

A.6.3. PRE-EMPLOYMENT EXAMINATION

Every worker should undergo a pre-employment medical examination, including a careful medical history. The medical history and medical examination findings are important and can be used for the following purposes:

- as a basis for determining fitness for work
- as a reference point to determine any subsequent change which may be due to occupational exposure or which may alter the worker’s fitness for work
- as possible source material for later epidemiological studies.

11 Reproduced from IAEA Safety Series No.43.
A.6.3.1. Pre-employment history

A careful medical and occupational history should be obtained on pre-employment examination. The following points should be especially noted:

(a) Smoking history — a history of personal tobacco use. Cigarette smoking is important in workers exposed to inhaled radioactivity.
(b) Family history — any family history of cancer or blood disorders.
(c) Occupational history — a history of previous occupational exposure to ionizing radiation in any form. Occupational exposure to other potential cancer-producing substances, e.g. benzene, should be noted. The occupational history should also enquire into any previous mining and dust exposure.
(d) Medical history — a history of radiological examinations and radiotherapies. Some estimate of the dose from medical irradiation should be made.
(e) Respiratory system diseases — frequency of cough, frequency of phlegm production with cough, chest pain and shortness of breath.

A.6.3.2. Details of the pre-employment examination

A complete medical examination as described below should be carried out. This examination should be done preferably before commencing work, but not earlier than two months before commencing such work. The examination should include the following:

(a) General data on height, weight and body build.
(b) Examination of the respiratory system. This should include a chest X-ray (if this is not available within the previous 12 months) and certain pulmonary function tests, e.g. vital capacity and forced expiratory volume.
(c) Examination of the cardiovascular system. Blood pressure should be recorded. Where indicated, because of age or medical history, an electrocardiogram and exercise test should be included.
(d) Haematological examination. This should include haemoglobin level, red cell count, white cell count, thrombocyte count and examination of a stained blood film for differential count and appearance of atypical blood cells.
(e) Examination of the kidneys. This should include urinalysis for determination of albumin, glucose and cellular content.
(f) Examination of the skin. This should determine whether any chronic skin condition is present.
(g) Ear, nose and throat examination. This should include audiometric examination because noise exposure in mining and milling of ores may be significant.
(h) Examination of the eyes. A test of visual acuity should be done as well as an examination for evidence of any ocular disease.
(i) Gastro-intestinal examination.
(j) Liver function. Specific tests of liver function should only be done where deemed necessary, e.g. BSP retention, transaminase or blood albumin and globulin levels.
(k) Neurological examination. This should include a routine examination of neurological functions.
(l) Mental health. The examination should take note of the general intellectual level of the worker and his general emotional health.
(m) Special examinations. Other examinations may be carried out in special cases to determine base-line levels, e.g. chromosome studies, sputum cytology, uranium in urine, a count of binucleated lymphocytes in peripheral blood, etc. These, however, should not be considered as part of the routine pre-employment examination.
(n) Musculoskeletal examination. This should look out for diseases of the bones and muscles and for deformities, arthritis, myasthenia gravis, etc.

A.6.3.3. Conclusion of the pre-employment examination

(a) The history and medical examination should provide information for the Medical Practitioner to determine the worker's fitness for a given type of work. The final conclusion is a matter within the Medical Practitioner's professional discretion. A suggested list of contraindications for work in mining and milling of uranium and thorium is provided for general guidance.\(^{12}\)

(b) The Medical Practitioner's recommendation to the employer should state that the worker is in one of the following categories:
   (i) Fit for all types of work
   (ii) Fit for work with specific qualifications, e.g.
        no work at heights
        no work with noise exposure
        no work with exposure to dust and fumes
   (iii) Unfit for work.

(c) The Medical Practitioner should inform the employee of which category he was placed in and why. Any other abnormalities of importance to his general health should be reported to the employee, and if he smokes cigarettes, he should be advised of the extra risk involved of developing lung cancer.

A.6.4. PERIODIC MEDICAL EXAMINATIONS

The periodic medical examination should pay attention to the organ systems likely to be the ones most affected by exposure to environmental hazards in

\(^{12}\) Appendix V of IAEA Safety Series No. 43.
mining and milling of radioactive ores. In addition to exposure to radioactive substances, there may be exposure to pneumoconiosis-producing dusts, e.g. silica, and to noise, etc. It should also be remembered that the systemic toxicity of soluble uranium compounds may be more important than their radiotoxicity, with the kidney as the critical organ. The periodic examination should be carried out at appropriate intervals — generally once each year. It should consist of a general examination and functional check, and should include pulmonary function tests, blood pressure measurement, haematological examination, radiochemical and other analyses, and audiometric examination as described above. Chest X-rays should be obtained at five-year intervals except if prescribed more frequently for special examinations.

Other special examinations may be carried out on a periodic basis where considered necessary (see Section A.6.6). Records of the results of the periodic examination and any special examination should be entered into the worker's medical file.

A.6.5. MEDICAL EXAMINATION AT TERMINATION OF EMPLOYMENT AND FURTHER MEDICAL FOLLOW-UP

All persons who have worked in mining and milling of radioactive ores should undergo, free of charge, a medical examination upon termination of their employment.

Depending on the results of this examination and on the professional judgment of the Medical Practitioner, it may be necessary to provide further periodic and follow-up examinations after employment has ceased. The necessary follow-up procedure should also be carried out at no expense to the worker.

A.6.6. SPECIAL PROCEDURES OF MEDICAL SUPERVISION

The medical supervision of mine and mill workers comprises the pre-employment examination, the periodic examinations, the examination on termination of employment and other special procedures. Such special procedures are the following:

(a) Supplementary radiochemical and other analyses should be made, if necessary, for assessing the radiation dose received by the worker and consolidating the information from the periodic examination.

(b) Analysis for uranium in urine should be carried out where appropriate, e.g. for mill operators. A uranium concentration in urine exceeding 60 μg per day should be considered as an 'investigation level' calling for review of the working conditions or the personal hygiene measures of the worker involved.
(c) Semi-annual examinations of exfoliated bronchial cells in the sputum should be made for all workers exposed to radiation in uranium mining for 10 years or more.

A.6.7. POST-ILLNESS PRECAUTION

The medical supervision of workers should include the examination of the respiratory tract for conditions which might affect the deposition pattern of inhaled particles. Bronchial ciliary action is an important mechanism for the clearance of inhaled particles, particularly during the first 24 hours. Smoking and conditions of chronic cough and bronchitis may seriously affect the ciliary mechanism. Medical supervision should ensure that the worker upon return from illness is fit to resume work.

A.6.8. MEDICAL ADVICE TO MINE MANAGEMENT

The Medical Practitioner should advise the management as to the suitability of individual workers for employment in mining and milling of radioactive ores. The results of the pre-employment examination should be forwarded to the management.

The Medical Practitioner should periodically advise the management on the fitness of a worker. If a worker is found unfit for the specific work he has been assigned, the Medical Practitioner should indicate whether the condition is temporary or permanent. If, in his opinion, the particular ailment could have resulted from unsuitable working conditions, he should also advise the management on the need for correction.

A.6.9. PERSONAL HEALTH RECORDS

A.6.9.1. Medical records

Reports of pre-employment, periodic, special or termination medical examinations of employees should be maintained during employment and for a period of no less than 30 years after the cessation of work with radioactive minerals.

The medical records of workers are confidential and should be handled and treated in a confidential fashion. The confidentiality, however, does not restrict the access of a worker to his own records. They should be kept in the care of the medical organization. Medical records, laboratory reports, etc. include Medical
Practitioner reports, sickness reports, medical history reports, etc. Records of individual radiation exposure should not be considered as confidential medical records.

A.6.9.2. Radiation exposure records

Records of internal or external radiation exposures and of bio-assays in respect of each individual worker should be maintained during employment and, after the cessation of work with radioactive minerals, for a period of no less than 30 years. It may be emphasized that the records of radiation exposures of individual workers should be available for the continuity of cumulative exposure calculations as workers change employment.

In addition, monitoring records, including measurements of external radiation, radon and thoron and their daughters, and long-lived radionuclides, should be maintained.
Appendix A.I

EXAMPLE OF REFERENCE LEVEL PROGRAMME FOR A URANIUM MINE-MILL FACILITY USED IN CANADA (underground mine)

RADIATION EXPOSURE CONTROL

<table>
<thead>
<tr>
<th>REFERENCE LEVEL</th>
<th>PROTECTIVE ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Concentration range of radon daughters)</td>
<td></td>
</tr>
<tr>
<td>1.1. 0 — 0.30 WL</td>
<td>(a) Measure radon daughter concentration in each working place to ensure that exposure levels are maintained within the AECB(^a) criteria of 50% accuracy at 95% confidence limits.</td>
</tr>
<tr>
<td></td>
<td>(b) When significant increases occur, investigate and take remedial measures when practical.</td>
</tr>
<tr>
<td>1.2. Greater than 0.3 WL and up to 0.65 WL</td>
<td>(a) Measure radon daughter concentrations in each working place to ensure that exposure levels are maintained within the AECB exposure criteria.</td>
</tr>
<tr>
<td></td>
<td>(b) Ventilation Engineer will investigate and implement remedial measures where practical to ensure that levels are maintained as low as reasonably achievable.</td>
</tr>
<tr>
<td></td>
<td>(c) Ventilation Engineer will conduct field investigation; corrective action is conducted in co-operation with the immediate production personnel; requests for further corrective action may be made in writing to the Mine Captain or Area Foreman.</td>
</tr>
<tr>
<td></td>
<td>(d) Ventilation Engineer will report occurrence to the Environmental Superintendent or his appointed delegate.</td>
</tr>
</tbody>
</table>

\(^a\) AECB — Atomic Energy Control Board, competent authority.
<table>
<thead>
<tr>
<th>REFERENCE LEVEL</th>
<th>PROTECTIVE ACTION</th>
</tr>
</thead>
</table>
| 1.3. Greater than 0.65 WL and up to 1.25 WL | (a) Normal operation may continue for the ensuing 48 h.  
(b) If normal operations are to continue at above 0.65 WL beyond the ensuing 48 h, all personnel so continuously exposed are to use respiratory protection on confirmation by the Environmental Superintendent.  
(c) Ventilation Engineer will measure radon daughter concentrations at daily intervals until below 0.65 WL.  
(d) Ventilation Engineer will conduct an immediate field investigation; to be conducted in co-operation with immediate production personnel, with all necessary corrective actions being prompt and continuous, not awaiting written reports. Notification and details of corrective action are to be made in writing within 24 h to the Mine Captain or Area Foreman.  
(e) Ventilation Engineer will report the occurrence to the Environmental Superintendent or his appointed delegate. |
| 1.4. Greater than 1.25 WL and up to 3.00 WL | (a) Resample the site and consider the high sample confirmed if the average of three consecutive samples is in excess of 1.25 WL. This action must be completed within 2 h of the original sample and corrective action may be initiated within that period.  
(b) Ventilation personnel will suspend all operations in the working place immediately.  
(c) The working area so affected shall be designated a restricted area and posted accordingly by ventilation personnel.  
(d) Ventilation Engineer will report the occurrence to the Environmental Superintendent or his appointed delegate.  
(e) Ventilation Engineer will determine the corrective action necessary to restore acceptable conditions.  
(f) Mandatory approved powered respiratory protection will be worn by personnel engaged in work to restore acceptable conditions (0.65 WL or below). |
### REFERENCE LEVEL PROTECTIVE ACTION

<table>
<thead>
<tr>
<th>1.4. Greater than 1.25 WL and up to 3.00 WL (cont.)</th>
<th>(g) Ventilation Engineer will measure radon daughter concentrations in active working places daily until concentrations are below 0.65 WL.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5. Greater than 3.0 WL</td>
<td>Procedure as above for 1.25 WL to 3.0 WL, with the addition that the Manager will notify those persons appointed by the AECB and listed in the appropriate Facility Licence of the occurrence and resumption of normal operations.</td>
</tr>
</tbody>
</table>

**Gamma exposure rate**

<table>
<thead>
<tr>
<th>2.1. 2.5 mR·h(^{-1}) or greater</th>
<th>Area will be posted as per Part IV, Section 22(4), of the Atomic Energy Control Regulations.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2. 5 mR·h(^{-1}) or greater</td>
<td>Access will be restricted and decontamination initiated, if appropriate. Work procedures may have to be modified, if practicable.</td>
</tr>
</tbody>
</table>

**Gamma dose equivalent**

(millirem per 3 months)

<table>
<thead>
<tr>
<th>3.1. Less than 500 (5.0 mSv)</th>
<th>No individual action required, but evaluate the average dose for workers by job classification.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2. 501–750 (5.01–7.50 mSv)</td>
<td>(a) Verify the exposure and investigate the cause. (b) Evaluate the average dose for workers by job classification.</td>
</tr>
<tr>
<td>3.3. 751–1000 (7.51–10.0 mSv)</td>
<td>(a) Initiate actions to identify and, if possible, alleviate the cause of the gamma exposure. (b) Evaluate the average dose for workers by job classification.</td>
</tr>
<tr>
<td>3.4. Greater than 1000 (10.0 mSv)</td>
<td>(a) Initiate actions to identify the cause; take the necessary steps to minimize the exposure where no practical corrective action is identified. (b) Evaluate the average dose for workers by job classification.</td>
</tr>
</tbody>
</table>

---

\(^b\) Although there is an SI equivalent for röntgen (1 R = 258 µC·kg\(^{-1}\)), there is as yet no international agreement as to the form in which exposure or an equivalent idea will in future be expressed.
### Gamma dose equivalent (millirem per 6 months)

<table>
<thead>
<tr>
<th>Level</th>
<th>Protective Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5. Less than 1000 (10.0 mSv)</td>
<td>No individual action required, but evaluate the average dose for workers by job classification.</td>
</tr>
</tbody>
</table>
| 3.6. 1001–2000 (10.1–20.0 mSv) | (a) Initiate actions to identify and if possible alleviate the cause of the gamma exposure.  
                                    (b) Evaluate the average dose for workers by job classification. |
| 3.7. Greater than 2000 (20.0 mSv) | (a) Initiate actions to identify the cause and take the necessary steps to minimize the exposure where no practical corrective action is identified.  
                                    (b) Evaluate the average dose for workers by job classification. |

4. Notwithstanding any limitation of this Reference Level Programme, the Manager may, in writing, authorize any person to enter any part of the mine if entry is essential for the protection of life or property, or for the purpose of training operating personnel in emergency measures.

5. Without prejudice to the generality of the paragraph above or to any authority or exemption given under this Reference Level Programme, the Manager may stipulate the nature and type of personal protective equipment during entry to any part of a mine. However, to meet the Atomic Energy Control Board's approval for the application of respirator credit to the exposure estimates, the respiratory device must be of a suitable positive pressure type.

6. The Manager shall ensure that every inspection, examination or activity required under this Reference Level Programme be assigned to a competent person or persons appointed by him, and be carried out by the competent person or persons so appointed.

7. For the purposes of this Reference Level Programme, the 'Manager' means the 'Mine Manager'.

It is recognized that job rotation is not a substitute for good ventilation control and in the past the degree of ventilation control has permitted employee exposure limits to be met without resorting to job rotation. Nevertheless, individual employee exposures to radon daughters are calculated on a monthly basis and reviewed by the Ventilation Engineer. The maximum permissible exposures to radon daughters are 4 WLM per year and 2 WLM in a calendar quarter. Should any employee be accumulating exposure at a rate exceeding 0.6 WLM per month or exceed 75% of either maximum permissible exposure, his/her situation would be reviewed. If immediate reductions in his/her exposure rate were not expected, then the employee would be recommended for reassignment to a lower-level exposure area by the Ventilation Engineer, the Department Head involved, and the Environmental Superintendent.
EXAMPLE OF REFERENCE LEVEL PROGRAMME
FOR A URANIUM MINE-MILL FACILITY USED IN CANADA
(very high-grade open pit mine)

RADIATION EXPOSURE CONTROL

<table>
<thead>
<tr>
<th>REFERENCE LEVEL</th>
<th>PROTECTIVE ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Radon daughters</td>
<td>Routine monitoring to ensure that the levels are maintained within the AECB(^a) criterion of 50% accuracy at 95% confidence limit.</td>
</tr>
<tr>
<td>(i) 0—0.05 WL</td>
<td>Levels to be monitored daily.</td>
</tr>
<tr>
<td>(ii) Greater than 0.05 WL and up to 0.11 WL</td>
<td>(a) Levels to be monitored daily. (b) In addition, for the 'X' orebody open pit — Area will be posted as an AIRBORNE RADIATION AREA. — All personnel entering pit without alpha dosimeter will be required to sign log book. — Measurement will be posted.</td>
</tr>
<tr>
<td>(iii) Greater than 0.11 WL and up to 0.25 WL</td>
<td>(a) Investigation initiated to determine cause. Corrective action will be taken as soon as reasonably practicable. (b) Area resampled after 4 h. (c) In addition, for the 'X' orebody open pit — Yellow flag shall be hoisted. — Admittance of any person without respiratory protection or not in positively ventilated equipment cabs limited to two hours.</td>
</tr>
<tr>
<td>(iv) Greater than 0.25 WL and up to 0.50 WL</td>
<td>(a) As for (iii) above. (b) Airborne radiation warning sign posted. (c) Admittance of any person without respiratory protection or not in positively ventilated equipment cab limited to one hour per day. (d) Foreman shall be notified immediately with a follow-up in writing.</td>
</tr>
</tbody>
</table>

\(^a\) AECB — Atomic Energy Control Board, competent authority.
<table>
<thead>
<tr>
<th>REFERENCE LEVEL</th>
<th>PROTECTIVE ACTION</th>
</tr>
</thead>
</table>
| (v) Greater than 0.50 WL and up to 1.00 WL | (a) Immediate investigation and corrective action shall be taken.  
(b) Airborne radiation sign posted.  
(c) Area resampled after two hours.  
(d) Admittance by a person without respiratory protection prohibited.  
(e) Superintendent shall be notified immediately with a follow-up in writing.  
(f) Director of RPHS and EP shall be notified.  
(g) In addition, for the ‘X’ orebody  
   — Red flag shall be posted.  
   — All normal operations shall cease. |
| (vi) Greater than 1.00 WL and up to 2.00 WL (based on the average of three samples taken in a two-hour period) | (a) As for (v) above.  
(b) Manager shall be notified immediately with a follow-up in writing.  
(c) All production operations suspended in the area.  
(d) The AECB shall be notified within 24 h. |
| (vii) Greater than 2.00 WL (sampled as in (vi) above) | (a) As for (vi) above.  
(b) Access to the area shall be prohibited. |

2. Gamma exposure rate

| (i) 0—1.5 mR · h⁻¹ | Routine monitoring to ensure that level is maintained. |
| (ii) Greater than 1.5 mR · h⁻¹ and up to 2.5 mR · h⁻¹ | (a) Investigation initiated to determine cause. Remedial action shall be taken as soon as reasonably practicable.  
(b) In addition, for the ‘X’ orebody open pit  
   — Area will be clearly marked by stakes. |
| (iii) Greater than 2.5 mR · h⁻¹ and up to 10 mR · h⁻¹ | (a) As for (ii) above.  
(b) Gamma radiation warning sign posted.  
(c) Foreman shall be notified.  
(d) Access by production personnel to the area shall be controlled. |
| (iv) Greater than 10 mR · h⁻¹ | (a) As for (iii) above.  
(b) Superintendent shall be notified with a follow-up in writing.  
(c) Director RPHS and EP shall be notified.  
(d) Access by production personnel to the area shall be controlled. |

b Radiation Protection, Health-Safety and Environmental Protection.

c Although there is an SI equivalent for röntgen (1 R = 258 μC · kg⁻¹), there is as yet no international agreement as to the form in which exposure or an equivalent idea will in future be expressed.
3. Uranium in urine

All employees designated as atomic radiation workers shall submit a urine sample for analysis once each month during their work shift.

<table>
<thead>
<tr>
<th>REFERENCE LEVEL</th>
<th>PROTECTIVE ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. First sample</strong></td>
<td></td>
</tr>
<tr>
<td>(i) 0—25 μg · L⁻¹</td>
<td>Routine monitoring to ensure that this level is maintained.</td>
</tr>
<tr>
<td>(ii) Greater than 25 μg · L⁻¹ and up to 50 μg · L⁻¹ (for two successive monthly samples)</td>
<td>Employee's work and hygiene habits discussed with employee and supervisor.</td>
</tr>
<tr>
<td>(iii) Greater than 50 μg · L⁻¹</td>
<td>Resample (if possible in same week).</td>
</tr>
<tr>
<td><strong>B. Second sample</strong></td>
<td></td>
</tr>
<tr>
<td>(i) 0—25 μg · L⁻¹</td>
<td>(a) Employee advised. (b) No further action.</td>
</tr>
<tr>
<td>(ii) Greater than 25 μg · L⁻¹ and up to 50 μg · L⁻¹</td>
<td>Employee's work and hygiene habits discussed with employee and supervisor.</td>
</tr>
<tr>
<td>(iii) Greater than 50 μg · L⁻¹ and up to 100 μg · L⁻¹</td>
<td>(a) As for (ii) above. (b) Resample at start of next week.</td>
</tr>
<tr>
<td>(iv) Greater than 100 μg · L⁻¹</td>
<td>(a) As for (ii) above. (b) Check for albumin in urine. (c) Director RPHS and EP notified. (d) Resample daily.</td>
</tr>
<tr>
<td>(v) Greater than 150 μg · L⁻¹</td>
<td>(a) As for (iv) above. (b) Resident Manager notified in writing. (c) Employee will be removed from work areas where exposure may be significant.</td>
</tr>
<tr>
<td><strong>C. Subsequent samples</strong></td>
<td></td>
</tr>
<tr>
<td>(i) 0—50 μg · L⁻¹ (for two successive samples under (iv) or (v) above)</td>
<td>(a) Discontinue sampling. (b) Employee may return to regular work.</td>
</tr>
<tr>
<td>(ii) Greater than 50 μg · L⁻¹</td>
<td>Resample on same schedule.</td>
</tr>
</tbody>
</table>
NOTES

1. Radon daughter measurements are to be taken in the normal breathing zone.

2. Gamma measurements are to be taken at one metre above the ground and at one metre from a probable source, except where a 'working station' is in closer proximity to the source, in which case the field at the 'working station' will be measured.

3. Radiation warning signs will show:
   (a) Type of hazard (i.e. GAMMA or RADON DAUGHTER)
   (b) Maximum observed level within the area to which the sign refers
   (c) Level at the sign and/or warning barrier (if significantly different from the maximum)
   (d) Date and time of most recent sampling for which a significant change was observed
   (e) Protective actions required by employees, e.g.
      - RESPIRATORY PROTECTION REQUIRED FOR EXPOSURE OVER ONE HOUR
      - RESPIRATORY PROTECTION REQUIRED
      - NO ADMITTANCE
      - ADMITTANCE LIMITED TO ONE HOUR.

4. 'Action to be taken' refers only to those areas in which employees are, or may be, working.

5. Notwithstanding any limitation of this Reference Level Programme, the Manager or Director RPHS and EP may authorize any person in writing to enter any part of the mine if entry is essential for the protection of life or property, or for the purpose of training operating personnel in emergency measures.

   Without prejudice to the generality of the paragraph above or to any authority or exemption given under this Reference Level Programme, the Manager or Director RPHS and EP may stipulate the nature and type of personal protective equipment during entry to any part of a mine. However, to meet the Atomic Energy Control Board's approval for the application of respirator credit to the exposure estimates, the respiratory device must be of a suitable positive pressure type.

6. The Director RPHS and EP shall ensure that every inspection, examination or activity required under this Reference Level Programme be assigned to a competent person or persons appointed by him, and be carried out by the competent person or persons so appointed.

DEFINITIONS

Superintendent:
   The mine or mill superintendent (as appropriate) or in the case of his absence from the site the senior supervisor of the department, i.e. Assistant Superintendent or General Foreman.

Manager:
   The senior person on-site responsible for operations, e.g. Mine Manager or designated Superintendent.

Director RPHS and EP:
   The person holding this position or other person designated by him during any extended period when he is unavailable.

Foreman:
   The on-site supervisor responsible for the operation of the mine or mill (as appropriate), i.e. Shift Boss, Acting Shift Boss, or General Foreman.
REFERENCES TO TECHNICAL ADDENDUM


This publication is no longer valid
Please see http://www-ns.iaea.org/standards/
GLOSSARY

DEFINITIONS AND EXPLANATIONS OF TERMS USED

absorbed dose: The absorbed dose, \( D \), is the quotient of \( \bar{d} \) by \( dm \), where \( \bar{d} \) is the mean energy imparted by ionizing radiation to matter of mass \( dm \) [ICRU* Report 33]:

\[
D = \frac{\bar{d}}{dm}
\]

The special name for the SI unit of absorbed dose is gray (Gy):

\( 1 \text{ Gy} = 1 \text{ J} \cdot \text{kg}^{-1} \).

The special unit of absorbed dose, rad, may be used temporarily:

\( 1 \text{ rad} = 10^{-2} \text{ Gy} \).

annual limit on exposure (ALE): The exposure to an airborne radionuclide, expressed as the time integral of concentration, which would result in the Reference Man inhaling the annual limit on intake for that radionuclide.

annual limit on intake (ALI): The ALI is a secondary limit for occupational internal exposure and is the smaller value of intake of a given radionuclide in a year by Reference Man [ICRP Publication 23] which would result in either a committed effective dose equivalent of 50 mSv or a committed dose equivalent in the lens of the eye of 150 mSv or in any other organ or tissue of 500 mSv.

competent authority: A national authority designated or otherwise recognized as competent authority by the government of a state for a specific purpose in connection with this publication.

contamination, radioactive: A radioactive substance in a material or place where it is undesirable.

controlled area: An area subject to special rules for the purposes of protection against ionizing radiation and to which access is controlled.

* International Commission on Radiation Units and Measurements, Washington, DC.
derived air concentration (DAC): The DAC for a given radionuclide is a derived limit and is the activity concentration of that radionuclide in air (Bq·m⁻³) which, if breathed by Reference Man [ICRP Publication 23] for a working year of 2000 hours under conditions of light physical activity (breathing rate 1.2 m³·h⁻¹), would result in an inhalation of one ALI, or the concentration which for 2000 hours of air immersion would lead to the irradiation of any organ or tissue to the appropriate limit.

derived limits: Derived limits are related to primary limits by a defined model such that if the derived limits are observed, it is likely that the primary limits would also be observed.

dose equivalent: The dose equivalent, H, is the product of D, Q and N at the point of interest in tissue, where D is the absorbed dose, Q is the quality factor and N is the product of all other modifying factors [ICRU Reports 25, 33]:

\[ H = DQN \]

The SI unit for H is the same as that for D (joule per kilogram).
The special name for the SI unit of dose equivalent is sievert (Sv):
1 Sv = 1 J·kg⁻¹.
The special unit of dose equivalent, rem, may be used temporarily:
1 rem = 10⁻² Sv.
Currently ICRP assigns a value of unity to N.

dose-equivalent indices: Two dose-equivalent indices are defined:
(a) deep dose-equivalent index, \( H_{ld} \), at a point is the maximum dose equivalent within the 28 cm diameter core of a 30 cm diameter sphere centred at this point and consisting of material equivalent to soft tissue with a density of 1 g·cm⁻³.
(b) shallow dose-equivalent index, \( H_{ls} \), at a point is the maximum dose equivalent within the spherical shell extending from a depth of 0.07 mm to a depth of 1 cm from the surface of a 30 cm diameter sphere centred at this point and consisting of material equivalent to soft tissue with a density of 1 g·cm⁻³.
(For a definition of dose-equivalent index, see ICRU Reports 25, 33.)

effective dose equivalent: The effective dose equivalent, \( H_E \), is defined as:

\[ H_E = \sum_{T} w_T H_T \]
where $H_T$ is the mean dose equivalent in tissue $T$ and $w_T$ is a weighting factor representing the proportion of the detriment from stochastic effects resulting from tissue $T$ to the total detriment from stochastic effects when the body is irradiated uniformly.

The values of $w_T$ are specified by ICRP [ICRP Publication 26] and are:

<table>
<thead>
<tr>
<th>Tissue</th>
<th>$w_T$</th>
<th>Tissue</th>
<th>$w_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gonads</td>
<td>0.25</td>
<td>Thyroid</td>
<td>0.03</td>
</tr>
<tr>
<td>Breast</td>
<td>0.15</td>
<td>Bone surfaces</td>
<td>0.03</td>
</tr>
<tr>
<td>Red bone marrow</td>
<td>0.12</td>
<td>Remainder</td>
<td>0.30</td>
</tr>
<tr>
<td>Lung</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A value of $w_T$ of 0.06 is applicable to each of the five organs or tissues of the remainder receiving the highest dose equivalents, and the exposure of all other remaining tissues may be neglected. (The following parts of the GI tract — stomach, small intestine, upper large intestine and lower large intestine — are to be treated as four different organs.) The dose equivalents in hands and forearms, feet and ankles, the skin, and the lens of the eye are not considered in computing the effective dose equivalent. However, to assess the detriment from exposure of population groups due to a small risk of fatal cancer resulting from exposure of the skin, a value of $w_T$ of 0.01 is assigned. The SI unit of effective dose equivalent is the joule per kilogram (J kg$^{-1}$). The special name for this unit is the sievert (Sv).

exposure (radon or thoron daughters): The exposure to radon and thoron daughters is expressed in terms of the time integral of their concentration in air. When the concentration is given in working levels (WL), the exposure is given in working level months (WLM), where the working month is 170 hours. When the derived air concentration is given in Bq m$^{-3}$, the exposure is expressed in Bq h m$^{-3}$. When the concentration is given in J m$^{-3}$, the exposure is expressed in J h m$^{-3}$.

exposure – external: Exposure to radiation sources outside the body. This is expressed in terms of the dose-equivalent indices.

exposure – internal: Exposure to radiation sources inside the body.

non-stochastic effects: Those effects for which the severity of the effect varies with the dose, and for which a threshold exists.
primary limits: The primary limits relate to the dose equivalent, effective dose equivalent, committed dose equivalent or committed effective dose equivalent, depending on the exposure circumstances. These limits apply to an individual or, in the case of exposure of the public, to the critical group.

quality factor, Q: This factor weights the absorbed dose in the definition of dose equivalent. The values of Q are specified by ICRP [see ICRP Publication 26 or Annex II of the IAEA Safety Series No.9 on Basic Safety Standards for Radiation Protection — 1982 Edition].

radioactive substance: Any substance which spontaneously emits ionizing radiations.

radioactivity: The activity, A, of an amount of radioactive nuclide in a particular energy state at a given time is the quotient of dN by dt, where dN is the expectation value of the number of spontaneous nuclear transformations from that energy state in the time interval dt [ICRU Report 33]:

\[ A = \frac{dN}{dt} \]

The special name for the SI unit of activity is becquerel (Bq):

1 Bq = 1 s\(^{-1}\).

The special unit of activity, curie (Ci), may be used temporarily:

1 Ci = 3.7 × 10\(^{10}\) Bq (exactly).

radon daughters: Short-lived decay products of \(^{222}\)Rn: \(^{218}\)Po (RaA), \(^{218}\)At, \(^{214}\)Pb (RaB), \(^{214}\)Bi (RaC), \(^{214}\)Po (RaC\(^{'}\)) and \(^{210}\)Tl (RaC\(^{''}\)).

reference levels: Reference levels may be established by the competent authority for any of the quantities determined in the course of radiation protection programmes, whether or not there are limits for these quantities. A reference level is not a limit and is used to determine a course of action when the value of a quantity exceeds or is predicted to exceed the reference level. The action to be initiated may range from simply recording the information, through investigations into causes and consequences, up to intervention measures. It is important to define the general scope of this action when defining the reference level. The most common forms of reference level are recording levels, investigation levels and intervention levels.

(a) Recording levels are monitoring results of dose-equivalent levels or intakes above which the result is of sufficient interest to be worth recording and keeping. Monitoring results below the recording level.
are simply stated as being below that level. These unrecorded results should be treated as zero for assessing the annual dose equivalent.

(b) **Investigation levels** are monitoring results indicating potential dose-equivalent or intake limits above which the results are considered sufficiently important to justify further investigations. For any defined type of measurement it is possible to derive an investigation level such that a measured result below the derived investigation level will, with reasonable certainty, correspond to a value of dose equivalent or intake below the relevant investigation level.

(c) **Intervention levels** are pre-determined levels above which action should be taken to reduce the radiation level or to remove personnel from exposure to that level until corrective actions can be implemented to reduce radiation levels to acceptable values.

**secondary limits:** Secondary limits are needed when the primary dose limits cannot be applied directly. In the case of external exposure, secondary limits may be expressed in terms of dose-equivalent index. In the case of internal exposure, secondary limits may be expressed in terms of annual limits on intake.

**stochastic effects:** Those effects for which the probability of an effect occurring, rather than its severity, is regarded to be a function of dose assumed to be without threshold.

**thoron daughters:** Short-lived decay products of $^{220}\text{Rn}$: $^{216}\text{Po (ThA)}, \, ^{212}\text{Pb (ThB)}, \, ^{212}\text{Bi (ThC)}, \, ^{212}\text{Po (ThC')}$, and $^{208}\text{Th (ThC'')}$. 

**working level (WL):** Any combination of radon daughters or thoron daughters in one litre of air that will result in the ultimate emission of $1.3 \times 10^5$ MeV of alpha energy. In SI units, the WL is equivalent to $2.1 \times 10^{-5}$ J m$^{-3}$.

**working level month (WLM):** A unit of exposure to radon or thoron daughters. One working level month is $3.54 \text{ mJ} \cdot \text{h} \cdot \text{m}^{-3}$ or $170 \text{ WL} \cdot \text{h}$. 

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