

IAEA SAFETY STANDARDS SERIES

Occupational Radiation Protection

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INTERNATIONAL ATOMIC ENERGY AGENCY AND THE
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SAFETY GUIDE

No. RS-G-1.1



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IAEA SAFETY STANDARDS

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OCCUPATIONAL RADIATION PROTECTION

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

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FOREWORD

**by Mohamed ElBaradei
Director General**

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

The following advisory bodies oversee the development of safety standards: the Advisory Commission on Safety Standards (ACSS); the Nuclear Safety Standards Advisory Committee (NUSSAC); the Radiation Safety Standards Advisory Committee (RASSAC); the Transport Safety Standards Advisory Committee (TRANSSAC); and the Waste Safety Standards Advisory Committee (WASSAC). Member States are widely represented on these committees.

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

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

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

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA.

Non-radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these.

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

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

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

PREFACE

Occupational exposure to ionizing radiation can occur in a range of industries, medical institutions, educational and research establishments and nuclear fuel cycle facilities. Adequate radiation protection of workers is essential for the safe and acceptable use of radiation, radioactive materials and nuclear energy.

In 1996, the Agency published *Safety Fundamentals on Radiation Protection and the Safety of Radiation Sources* (IAEA Safety Series No. 120) and *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources* (IAEA Safety Series No. 115), both of which were jointly sponsored by the Food and Agriculture Organization of the United Nations, the IAEA, the International Labour Organisation, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization. These publications set out, respectively, the objectives and principles for radiation safety and the requirements to be met to apply the principles and to achieve the objectives.

The establishment of safety requirements and guidance on occupational radiation protection is a major component of the support for radiation safety provided by the IAEA to its Member States. The objective of the IAEA's occupational protection programme is to promote an internationally harmonized approach to the optimization of occupational radiation protection, through the development and application of guidelines for restricting radiation exposures and applying current radiation protection techniques in the workplace.

Guidance on meeting the requirements of the Basic Safety Standards for occupational protection is provided in three interrelated Safety Guides, one giving general guidance on the development of occupational radiation protection programmes and two giving more detailed guidance on the monitoring and assessment of workers' exposure due to external radiation sources and from intakes of radionuclides, respectively. These Safety Guides together reflect the current internationally accepted principles and recommended practices in occupational radiation protection, with account taken of the major changes that have occurred over the past decade.

The three Safety Guides on occupational radiation protection are jointly sponsored by the IAEA and the International Labour Office.

The present Safety Guide provides general guidance on the establishment of an effective radiation protection programme for occupational exposure, in accordance with the requirements of the Basic Safety Standards and appropriate for the sources of radiation likely to be encountered in the workplaces in question.

EDITORIAL NOTE

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

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

The English version of the text is the authoritative version.

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1. INTRODUCTION

BACKGROUND

1.1. Occupational exposure to radiation can occur as a result of various human activities, including work associated with the different stages of the nuclear fuel cycle, the use of radioactive sources and X ray machines in medicine, scientific research, agriculture and industry, and occupations that involve the handling of materials containing enhanced concentrations of naturally occurring radionuclides.

1.2. The IAEA Safety Fundamentals publication “Radiation Protection and the Safety of Radiation Sources” [1] presents the objectives, concepts and principles of radiation protection and safety. Requirements designed to meet the objectives and apply the principles specified in the Safety Fundamentals, including requirements for the protection of workers exposed to sources of radiation, are established in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the Basic Safety Standards or BSS), jointly sponsored by the IAEA and five other international organizations [2].

1.3. Three interrelated Safety Guides, prepared jointly by the IAEA and the International Labour Office (ILO), provide guidance on fulfilling the requirements of the Basic Safety Standards with respect to occupational exposure. The present Safety Guide gives general advice on the exposure conditions for which monitoring programmes should be set up to assess radiation doses arising from external radiation and from intakes of radionuclides by workers. The other two Safety Guides give more specific guidance on the assessment of doses from external sources of radiation [3] and from intakes of radioactive materials [4]. The IAEA Safety Standards for occupational radiation protection are shown in Fig. 1.

1.4. Recommendations relating to occupational radiation protection have also been developed by the International Commission on Radiological Protection (ICRP) [5]. These and other current recommendations of the ICRP [6, 7] and the International Commission on Radiation Units and Measurements (ICRU) [7–9] have been taken into account in preparing this Safety Guide.

1.5. It is recognized that radiation protection is only one component that must be addressed to protect the overall health and safety of the worker. The radiation protection programme should be established and managed together with other health and safety disciplines, such as industrial hygiene, industrial safety and fire safety.

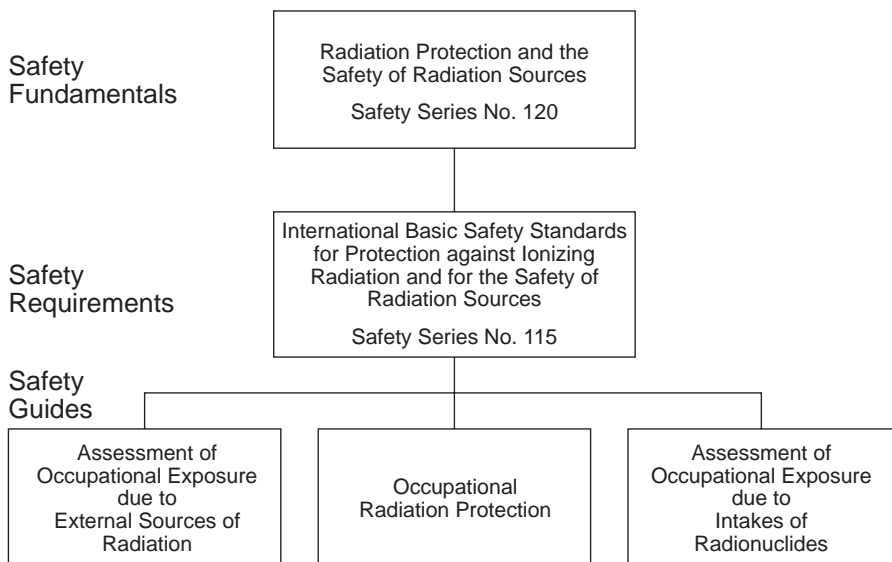


FIG. 1. IAEA Safety Standards for occupational radiation protection.

OBJECTIVE

1.6. The objective of this Safety Guide is to provide guidance on the control of occupational exposures, as defined more fully in Section 2. The recommendations given are intended for regulatory authorities, but this Safety Guide will also be useful to employers, licensees and registrants, to management bodies and their specialist advisers, and to health and safety committees concerned with the radiation protection of workers. The recommendations may also be used by workers and their representatives to encourage safe working practices.

SCOPE

1.7. This Safety Guide addresses the technical and organizational aspects of the control of occupational exposures, in situations of both normal and potential exposure. The intention is to provide an integrated approach to the control of normal and potential exposures due to external and internal irradiation from both artificial and natural sources of radiation.

STRUCTURE

1.8. Section 2 of this Safety Guide presents a framework of recommendations for meeting the requirements for occupational radiation protection and develops the definition of occupational exposure given in the BSS. A major subsection addresses the issue of application of the BSS to exposures to radiation from natural sources. Further subsections deal with radiation protection and safety matters, responsibilities and dosimetric quantities. Section 3 covers the practical application of the dose limits for occupational exposure, particularly the averaging of doses over five year periods. Section 4 deals with the optimization of protection and safety. Section 5 focuses on the development of a programme for radiation protection and safety, including recommendations for control of occupational exposure such as the classification of working areas, the assessment of doses to workers, training, record keeping and quality assurance. Section 6 provides guidance for workers intervening in an emergency. Section 7 covers the health surveillance of workers, based on the general principles of occupational health, and discusses the management of workers who have received doses above the dose limits.

2. FRAMEWORK FOR OCCUPATIONAL RADIATION PROTECTION

PRACTICES AND INTERVENTION

2.1. Two types of situation are defined for the purposes of establishing radiation protection principles: practices and interventions. Practices are those human activities that add radiation exposure to that which people normally receive from existing radiation sources, or that increase the likelihood of their incurring exposure. Interventions are human activities that seek to reduce the existing radiation exposure, or the likelihood of incurring exposure, and which are not part of a controlled practice. For a practice, provisions for radiation protection and safety can be made before its commencement, and the associated radiation exposures and their likelihood can be restricted from the outset. In the case of intervention, the circumstances giving rise to exposure or the likelihood of exposure already exist, and their reduction can only be achieved by means of protective or remedial actions.

2.2. Some radiation exposures resulting from the conduct of practices are virtually certain to occur, and their magnitudes will be predictable, albeit with some degree of

uncertainty. Such exposures are referred to in the BSS as ‘normal exposures’. In addition, scenarios can be envisaged in which there is a potential for exposure but no certainty that an exposure will actually occur. These unlikely but feasible exposures are termed ‘potential exposures’. The scope of the BSS encompasses both normal and potential exposures.

2.3. The BSS (Ref. [2], para. 3.1.) identify two types of intervention situation:

- “(a) emergency exposure situations requiring protective action to reduce or avert temporary exposures, including:
 - (i) accidents and emergencies in which an emergency plan or emergency procedures have been activated; and
 - (ii) any other temporary exposure situation identified by the Regulatory Authority or the Intervening Organization as warranting intervention; and
- (b) chronic exposure situations requiring remedial action to reduce or avert chronic exposure, including:
 - (i) natural exposure, such as exposure to radon in buildings and workplaces;
 - (ii) exposure to radioactive residues from past events, such as to the radioactive contamination caused by accidents, after the situation requiring protective action has been terminated, as well as from the conduct of practices and the use of sources not under the system of notification, and authorization; and
 - (iii) any other chronic exposure situation specified by the Regulatory Authority or the Intervening Organization as warranting intervention.”

2.4. The principal focus of this Safety Guide is the protection of workers in controlled practices. However, consideration is given to the protection of workers undertaking interventions in the event of an emergency (see Section 6). Situations in which intervention may be necessary to protect workers themselves are those most likely to involve chronic exposure, particularly from natural sources of radiation (see paras 2.16–2.30).

2.5. Examples of the practices to which the BSS apply are given in para. 2.1 of the BSS. They include the use of radiation or radioactive substances for medical or industrial purposes and for education, training or research, the generation of nuclear power and practices involving exposure to natural sources specified by the regulatory authority as requiring control. Examples of sources (within practices) to which the requirements of the BSS apply are given in para. 2.2 of the BSS. They include radioactive substances, sealed sources, radiation generators, irradiation facilities, mines and mills processing ores and nuclear installations.

OCCUPATIONAL EXPOSURE

2.6. The term ‘occupational exposure’ has been used by the ILO to refer to the exposure of a worker that is received or committed during a period of work [10]. However, the BSS (paras 1.4 and 2.17) provide for the exclusion of those exposures whose magnitude or likelihood is essentially unamenable to control, and for the exemption of those practices and sources within a practice that give rise to radiation risks that are sufficiently low as to be of no regulatory concern. In order that protective and preventive action can be focused and effective, the BSS give a more limited definition of occupational exposure, namely: “All exposures of workers incurred in the course of their work, with the exception of exposures excluded from the Standards and exposures from practices or sources exempted by the Standards” (Ref. [2], Glossary). It is these ‘occupational exposures’ that should be the responsibility of the operating management.

2.7. The BSS state that “Any exposure whose magnitude or likelihood is essentially unamenable to control through the requirements of the Standards is deemed to be excluded from the Standards” (Ref. [2], para. 1.4). Examples of such exposures given in the BSS are those from potassium-40 in the body, from cosmic rays at the earth’s surface, and from unmodified concentrations of radionuclides in most raw materials. Guidance is developed below on the components of exposure from natural sources of radiation that may need to be subject to control as occupational exposure.

2.8. The BSS state that practices and sources within a practice may be exempted from the requirements of the Standards provided that the regulatory authority is satisfied that such practices and sources comply with the requirements on exemption or the exemption levels based on them (Ref. [2], para. 2.17). Both the requirements and the exemption levels are specified in Schedule I of the BSS.

2.9. Schedule I of the BSS provides for the conditional exemption from the requirements of the Standards of radiation generators and apparatus containing radioactive substances in the form of sealed sources. One of the conditions in each case is that they should be of a type approved by the regulatory authority. This use of the exemption provision is likely to be of value with such devices as ionization chamber smoke detectors and radioactive starters for fluorescent tubes. With these devices, the exposures are effectively controlled through design. Further control of the exposure of those workers who may be working near where they are installed should not be necessary. This use of exemption implies the need to develop appropriate standards against which to judge whether the device should be type approved. However, despite such exemptions, the exposure of workers involved in the manufacture of exempt devices — or in their transport or maintenance — should still be subject to control.

2.10. The exposure of workers involved in protective or remedial actions in intervention situations is, in principle, controllable and should be regarded as being the responsibility of the operating management and therefore included as part of occupational exposure (see Section 6).

REFERENCE LEVELS

2.11. ‘Reference level’ is defined in the BSS as a general term that can refer to an action level, an intervention level, an investigation level or a recording level. Such levels are helpful in the management of operations as ‘trigger levels’ above which some specified action or decision should be taken. They may be expressed in terms of measurable quantities or in terms of any other quantities to which measured quantities can be related.

2.12. An action level is “The level of dose rate or activity concentration above which remedial actions or protective actions should be carried out in chronic exposure or emergency exposure situations” (Ref. [2], Glossary). Action levels often serve to protect members of the public, but they also have relevance in the context of occupational exposure in chronic exposure situations, particularly that involving exposure to radon in workplaces. This is discussed further in paras 2.16–2.30.

2.13. An intervention level is “The level of avertable dose at which a specific protective action or remedial action is taken in an emergency exposure situation or chronic exposure situation” (Ref. [2], Glossary). The use of this term is normally confined to interventions related to the protection of members of the public.

2.14. An investigation level is “The value of a quantity such as effective dose, intake, or contamination per unit area or volume at or above which an investigation should be conducted” (Ref. [2], Glossary), i.e. if investigation levels are exceeded, a review of the protection arrangements should be initiated to address the cause. The use of investigation levels is discussed more fully in Sections 4 and 5.

2.15. A recording level is “A level of dose, exposure or intake specified by the Regulatory Authority at or above which values of dose, exposure or intake received by workers are to be entered in their individual exposure records” (Ref. [2], Glossary). The use of recording levels is discussed in Section 5.

APPLICATION OF THE BSS TO NATURAL SOURCES OF RADIATION

2.16. The situation with regard to exposures from natural sources other than those mentioned in para. 2.7 needs further consideration. Because exposures from these

sources have, in many cases, not been subject to the same degree of regulatory control as exposures from artificial radiation sources, controls may need to be introduced where none were previously deemed necessary. The following text taken from the BSS (Ref. [2], paras 2.1, 2.2 and 2.5) provides the basis on which to build a protection policy for natural sources of radiation:

“The practices to which the Standards shall apply include:

- (a) the production of sources and the use of radiation or radioactive substances for medical, industrial, veterinary or agricultural purposes, or for education, training or research, including any activities related to that use which involve or could involve exposure to radiation or radioactive substances;

.....

- (c) practices involving exposure to natural sources specified by the Regulatory Authority as requiring control;”

“The sources within any practice to which the requirements for practices of the Standards shall apply include:

- (a) radioactive substances and devices that contain radioactive substances or produce radiation, including consumer products, sealed sources, unsealed sources, and radiation generators, including mobile radiography equipment;
- (b) installations and facilities which contain radioactive substances or devices which produce radiation, including irradiation installations, mines and mills processing radioactive ores, installations processing radioactive substances, nuclear installations, and radioactive waste management facilities; and
- (c) any other source specified by the Regulatory Authority.”

“Exposure to natural sources shall normally be considered as a chronic exposure situation and, if necessary, shall be subject to the requirements for intervention, except that:

- (b) occupational exposure of workers to natural sources shall be subject to the requirements for practices given in this section if these sources lead to:
 - (i) exposure to radon required by or directly related to their work, irrespective of whether the exposure is higher or lower than the action level for remedial action relating to chronic exposure situations involving radon in workplaces, unless the exposure is excluded or the practice or the source is exempted; or

- (ii) exposure to radon incidental to their work, but the exposure is higher than the action level for remedial action relating to chronic exposure situations involving radon in workplaces; unless the exposure is excluded or the source is exempted; or
- (iii) exposure specified by the Regulatory Authority to be subject to such requirements.”

2.17. The term ‘radioactive substance’ is not specifically defined in the BSS; it should be noted in particular that the term is not qualified by reference to artificial radionuclides only. Thus, the BSS are intended to apply to naturally occurring radionuclides that have been extracted from ores, irrespective of the use to which those radionuclides are put. Sealed and unsealed sources containing naturally occurring radionuclides such as radium-226 should therefore be treated as being within a practice.

2.18. From para. 2.5(b)(i) of the BSS, it is clear that the mining and milling of radioactive ores should be treated as practices. All exposures in these situations, including those from radon, should be subject to the requirements for practices, irrespective of whether the concentrations of radon in air are above the action level specified in the BSS.

2.19. Paragraph 2.5(b)(ii) of the BSS should be taken to mean that exposures to radon in workplaces other than those covered in para. 2.5(b)(i) should be subject to the requirements for occupational exposure if the radon concentration exceeds the action level. This does not, however, apply if the exposure has been excluded or the practice or source has been exempted. Examples of workplaces where exposure to radon is adventitious and the levels are likely to exceed the action level include mines (other than those intended to produce radioactive ores), spas and above-ground workplaces in radon prone areas.

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

2.21. The action level for radon in the workplace is given in the BSS as a yearly average concentration of 1000 Bq/m³, which would normally equate to an annual effective dose of about 6 mSv. This value is the midpoint of the range of 500–1500 Bq/m³ recommended by the ICRP [11], and some regulatory authorities may therefore wish to use a lower level than that specified in the BSS. It should be noted that the range of values given by the ICRP was based on an assumed equilibrium factor between radon and its progeny of about 0.4. There is practical advantage in adopting a single value for the action level which applies to all situations irrespective of the equilibrium factor. Nevertheless, although not explicitly stated in the BSS, other action levels may be appropriate if the equilibrium factor is significantly different from this, which may be the case in some mines.

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

2.23. The difficulty in applying an action level to new workplaces is that radon concentrations cannot be predicted with accuracy. They can only be determined following construction of the workplace. The implication is that the regulatory authority will need to establish a basis for identifying in advance those workplaces in which radon concentrations are likely to exceed the action level. The design and construction should then include preventive features and the action level applied after construction of the workplace as a check on the effectiveness of the preventive measures.

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

- (a) The mining, milling, handling and use of materials containing elevated levels of natural radionuclides (in addition to those ores from which uranium and thorium are extracted);
- (b) The presence of materials in which the activity concentration of natural radionuclides has been increased during processing, for example, in the deposits or scale sometimes found in the pipe work of oil rigs;
- (c) The increased exposure to cosmic radiation as a consequence of high altitude flight;
- (d) Where there are elevated gamma radiation dose rates due to the presence of natural radioactive substances in the ground and building materials that make up the workplace.

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

2.26. The approach applied to radon would not be appropriate for cases (a), (b) and (c) in para. 2.24. For these situations, it might be appropriate to specify particular groups of workers whose exposure should be subject to the requirements for practices, e.g. jet air crew. Another approach might be to define levels of annual dose or some other quantity above which the requirements would apply. These levels would then effectively act as a means of defining when the exposure is excluded or the practice or the source is exempted. In cases (a) and (b) in para. 2.24, an appropriate quantity to use for these levels would be activity concentration. For practical reasons, the regulatory authority may wish to use the levels as the basis for a quantitative definition of radioactive substance. For example, the exemption levels of activity concentration for the naturally occurring radionuclides, given in Schedule I of the BSS, or clearance levels could be used for this purpose.

2.27. In the situations described in parts (a) and (b) of para. 2.24, the handling and use of bulk quantities of minerals and other materials containing natural radioactive substances with activity concentrations in the range 1–10 Bq/g (of the parent radionuclide) could, under dusty conditions, result in an annual effective dose of about 1–2 mSv [5]. Experimental data on the exposure of workers to gamma radiation and dusts from the surface mining and milling of sedimentary phosphate ores containing about 1.5 Bq/g of uranium-238 support this assessment [12]. Control, if considered necessary, would include the use of methods to suppress or contain any airborne dusts and general radiological supervision.

2.28. The dose rate from cosmic rays varies with altitude, latitude, and the phase of the solar cycle. When considering cosmic ray exposure in jet aircraft (see para. 2.24(c)), a flying time of 200 h in a year at an altitude of 12 km is approximately equivalent to an annual effective dose of about 1 mSv [12]. The main action that could be taken would be to assess and record the occupational exposures of air crews and others whose doses exceed criteria specified by the regulatory authority. There may also be a need to consider the management of female air crew who have declared themselves to be pregnant (see para. 2.39). Additional information related to the exposure of air crews has been published by the European Dosimetry Group EURADOS [13].

2.29. When considering elevated gamma radiation dose rates (para. 2.24(d)), it may be appropriate to apply an approach similar to that for radon exposure not directly related

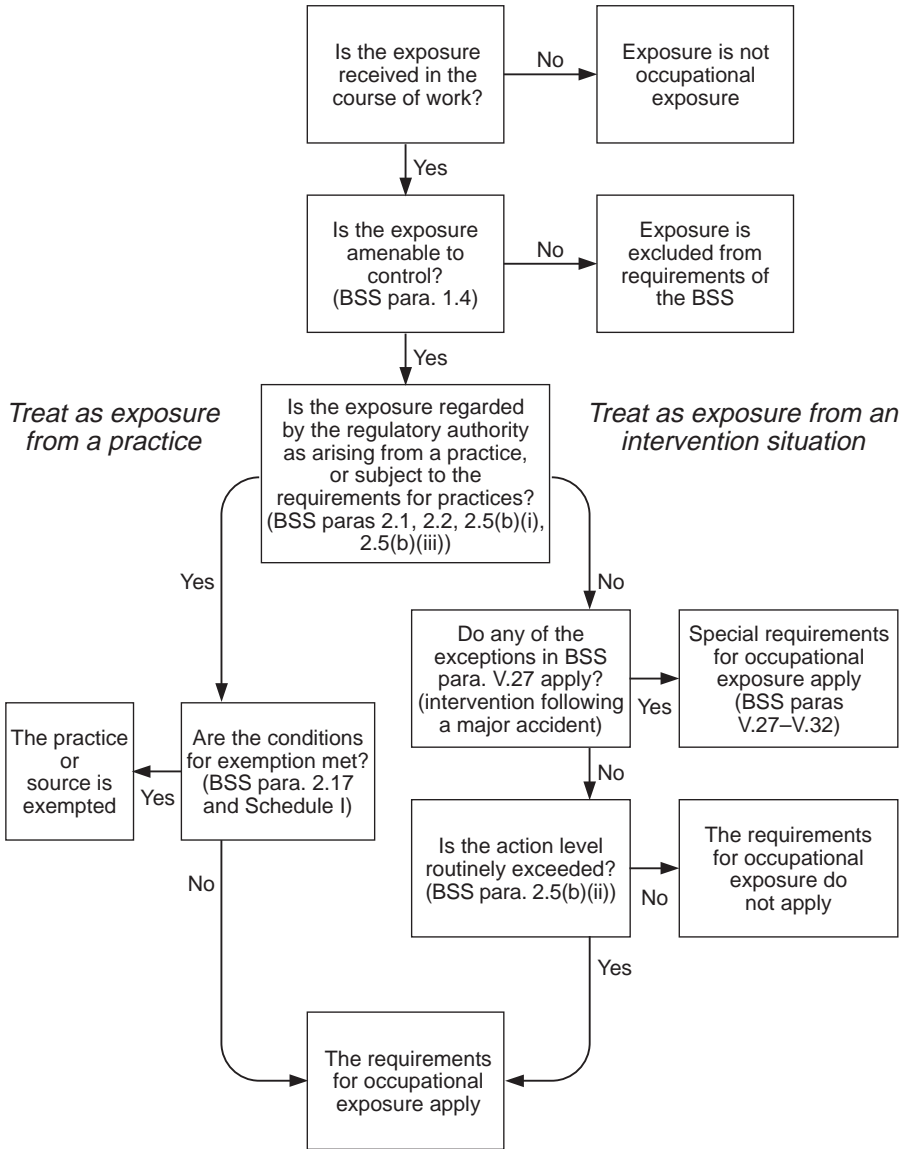


Fig. 2. Occupational exposure decision chart illustrating the tests that may be applied for each component (e.g. radon, external radiation, intake of radionuclides).

to work (discussed in para. 2.19). A gamma dose rate of 0.5 $\mu\text{Sv/h}$ for a working year (2000 h) would lead to an annual effective dose of about 1 mSv, and this dose rate or some multiple of it might be adopted as an action level. In the first instance, such cases would be treated as chronic exposure situations and be subject to the requirements for intervention. If the dose rate exceeded the action level chosen by the regulatory authority, consideration should be given to whether it could reasonably be reduced below the action level (for example, by shielding). If the dose rate could not be reasonably reduced below the action level, then the numerical value of the action level could be used to define when the requirements for practices should apply.

2.30. A summary of the approach to the definition and use of the term ‘occupational exposure’ is given in Fig. 2. It should be noted that identifying the exposure situations with natural sources of radiation that need attention may take a considerable time and it is therefore appropriate for the regulatory authority to develop a strategy that will allow the matter to be dealt with in a manageable way.

RADIATION PROTECTION REQUIREMENTS

2.31. The principles of radiation protection and safety for practices given in the BSS (Ref. [2], paras 2.20, 2.23 and 2.24) are as follows:

(a) Justification of practices

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

The process of determining whether a practice is justified involves consideration of all the radiation doses received by workers and members of the public. The assumption made in this Safety Guide is that the process of justification has already taken place and that the contribution of occupational exposure to the total radiation detriment has been taken into account. The subject of justification of practices is therefore not considered further in this Safety Guide.

(b) Dose limitation

“The normal exposure of individuals shall be restricted so that neither the total effective dose nor the total equivalent dose to relevant organs or tissues, caused by the possible combination of exposures from authorized practices, exceeds any relevant

dose limit specified in Schedule II, except in special circumstances provided for in Appendix I.”

The limit on effective dose represents the level above which the risk of stochastic effects due to radiation is considered to be unacceptable. For localized exposure of the lens of the eye, extremities and the skin, this limit on effective dose is not sufficient to ensure the avoidance of deterministic effects, and therefore limits on equivalent dose are specified for such situations. The application of the dose limits for occupational exposure in the BSS is discussed in Section 3 of this Safety Guide.

(c) Optimization of protection and safety

“In relation to exposures from any particular source within a practice, except for therapeutic medical exposures, protection and safety shall be optimized in order that the magnitude of individual doses, the number of people exposed and the likelihood of incurring exposures all be kept as low as reasonably achievable, economic and social factors being taken into account, with the restriction that the doses to individuals delivered by the source be subject to dose constraints.”

This principle, discussed in detail in Section 4, is of particular importance for the implementation of radiation protection measures in the workplace and therefore underlies much of the guidance given in this Safety Guide.

2.32. The basic obligations for intervention are that (Ref. [2], paras 3.3 and 3.4):

- (a) “In order to reduce or avert exposures in intervention situations, protective actions or remedial actions shall be undertaken whenever they are justified”; and
- (b) “The form, scale, and duration of any such protective action or remedial action shall be optimized so as to produce the maximum net benefit, understood in a broad sense, under the prevailing social and economic circumstances.”

RESPONSIBILITIES

Responsibilities of registrants, licensees and employers

2.33. In paras I.1 and I.2 (of Appendix I), the BSS (Ref. [2]) state that:

“Registrants and licensees and employers of workers who are engaged in activities involving normal exposures or potential exposure shall be responsible for:

- (a) the protection of workers from occupational exposure; and
- (b) compliance with any other relevant requirements of the Standards.”

and that “Employers who are also registrants or licensees shall have the responsibilities of both employers and registrants or licensees.”

2.34. In para. I.4, the BSS (Ref. [2]) state that, to fulfil their responsibilities:

“Employers, registrants and licensees shall ensure, for all workers engaged in activities that involve or could involve occupational exposure, that:

- (a) occupational exposures be limited as specified in Schedule II;
- (b) occupational protection and safety be optimized in accordance with the relevant principal requirements of the Standards;
- (c) decisions regarding measures for occupational protection and safety be recorded and made available to the relevant parties, through their representatives where appropriate, as specified by the Regulatory Authority;
- (d) policies, procedures and organizational arrangements for protection and safety be established for implementing the relevant requirements of the Standards, with priority given to design and technical measures for controlling occupational exposures;
- (e) suitable and adequate facilities, equipment and services for protection and safety be provided, the nature and extent of which are commensurate with the expected magnitude and likelihood of the occupational exposure;
- (f) necessary health surveillance and health services be provided;
- (g) appropriate protective devices and monitoring equipment be provided and arrangements made for its proper use;
- (h) suitable and adequate human resources and appropriate training in protection and safety be provided, as well as periodic retraining and updating as required in order to ensure the necessary level of competence;
- (i) adequate records be maintained as required by the Standards;
- (j) arrangements be made to facilitate consultation and co-operation with workers with respect to protection and safety, through their representatives where appropriate, about all measures necessary to achieve the effective implementation of the Standards; and
- (k) necessary conditions to promote a safety culture be provided.”

2.35. In summary, registrants, licensees and employers of workers are responsible for ensuring that exposures are limited (BSS para. I.4(a)), that protection and safety is optimized (BSS para. I.4(b)), and that appropriate radiological protection programmes are set up and implemented (BSS paras I.4(c)–(k)). The implications of the fulfilment

of these responsibilities are developed in a number of places in this Safety Guide. These responsibilities shall be placed on the management within the organizations of registrants, licensees or employers. For simplicity, the term ‘management’ will be used to denote ‘registrants, licensees and employers’ in the following sections of this Guide, except where there is a need to specify which entity is concerned.

Responsibilities of workers

2.36. Workers can by their own actions contribute to the protection and safety of themselves and others at work. The BSS (Ref. [2], para. I.10) specify that:

“Workers shall:

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

2.37. Workers are also responsible for providing feedback to the management, particularly when adverse circumstances arise related to the radiation protection programme. The BSS recommend that “If for any reason a worker is able to identify circumstances that could adversely affect compliance with the Standards, the worker shall as soon as feasible report such circumstances to the employer, registrant or licensee” (Ref. [2], para. I.11). In this case, the BSS prescribe that management “shall record any report received from a worker that identifies circumstances which could affect compliance with the Standards, and shall take appropriate action” (Ref. [2], para. I.12).

2.38. As it bears the prime responsibility for workers’ protection, management “shall facilitate compliance by workers with the requirements of the Standards” (Ref. [2], para. I.9). There are requirements in the BSS for management to provide appropriate

facilities for the protection of workers, and to train and consult them (through their representatives where appropriate) in the use of these facilities. Further guidance is given in the discussion of radiation protection programmes in Section 5.

2.39. Female workers and employers both have responsibilities regarding the protection of the embryo or foetus. The worker herself “should, on becoming aware that she is pregnant, notify the employer in order that her working conditions may be modified if necessary” (Ref. [2], para. I.16). When the pregnancy is notified, it “shall not be considered as a reason to exclude a female worker from work”, but it is the responsibility of the employer to “adapt the working conditions in respect of occupational exposure so as to ensure that the embryo or foetus is afforded the same broad level of protection as required for members of the public” (Ref. [2], para. I.17).

Co-operation between registrants, licensees and employers

2.40. The management of the occupational protection and safety of transient, temporary or itinerant workers, and others who are employed under contracts to organizations other than the operator, presents a major concern. In order that these workers are adequately protected and do not exceed any appropriate dose limit, there should be an adequate degree of co-operation between the employer, the workers (through their representatives where appropriate) and the management of the plants for whom contracts are being undertaken, whether those plants are within the same country or elsewhere. The BSS (Ref. [2], para. 1.30) state that:

“If workers are engaged in work that involves or could involve a source that is not under the control of their employer, the registrant or licensee responsible for the source and the employer shall co-operate by the exchange of information and otherwise as necessary to facilitate proper protective measures and safety provisions.”

(A self-employed person is regarded as having the duties of both an employer and a worker, as specified in the BSS definition of ‘worker’.) The BSS expand on this issue in a number of other related paragraphs. Regulatory authorities should therefore ensure that regulations exist requiring adequate protection and appropriate dose assessment for such workers, consistent with the standards applied to the workforce in general. The design of monitoring programmes referred to in Section 5 may need to address this situation specifically.

2.41. The BSS state (Ref. [2], para. I.31) that:

“The co-operation between the registrant or licensee and the employer shall include, where appropriate:

- (a) the development and use of specific exposure restrictions and other means in order to ensure that the protective measures and safety provisions for such workers be at least as good as those provided for employees of the registrant or licensee;
- (b) specific assessments of the doses received by such workers; and
- (c) a clear allocation and documentation of the respective responsibilities of the employer and the registrant or licensee for occupational protection and safety.”

2.42. The specific responsibilities assigned to registrant and licensee in this case include those stated in para. I.7 of Appendix I of the BSS (Ref. [2]):

“If workers are to be engaged in work that involves or could involve a source that is not under the control of their employer, the registrant or licensee responsible for the source shall provide:

- (a) appropriate information to the employer for the purpose of demonstrating that the workers are provided with protection in accordance with the Standards; and
- (b) such additional available information about compliance with the Standards as the employer may request prior to, during and after the engagement of such workers by the registrant or licensee.”

DOSIMETRIC QUANTITIES

2.43. The quantities in which the dose limits given in the BSS are expressed are the effective dose E and the equivalent dose H_T in tissue or organ T . These quantities are formally defined in the Glossary of the BSS. The quantity ‘effective dose’ is generally considered to be an adequate indicator of the health detriment from radiation exposure at the levels experienced in normal operations. A limit on equivalent dose is needed for skin and the lens of the eye in order to ensure the avoidance of deterministic effects in these tissues. The protection quantities E and H_T relate to the sum of the effective or equivalent doses received from external sources within a given time and the committed effective or equivalent doses from intakes of radionuclides that occurred within that time.

2.44. The basic quantities for physical measurement of external radiation exposure include kerma K and absorbed dose D , which are also formally defined in the Glossary of the BSS. Such quantities are used by national standards laboratories. The need for readily measurable quantities that can be related to effective dose and equivalent dose has led to the development of operational quantities for the assessment of external exposure. Defined by the International Commission on

Radiation Units and Measurements (ICRU) [8, 9], the operational quantities provide an estimate of effective or equivalent dose that avoids underestimation and excessive overestimation in most radiation fields encountered in practice [7]. The operational quantities for area monitoring are ambient dose equivalent $H^*(d)$ and directional dose equivalent $H'(d,\Omega)$, where d is the depth in the ICRU sphere in millimetres. The operational quantity for use in individual monitoring is the personal dose equivalent $H_p(d)$ at the specific depth d in soft tissue. By using the operational quantities $H^*(10)$ or $H_p(10)$, one obtains approximate values for the effective dose. By using the operational quantities $H_p(0.07)$ or $H'(0.07)$, one obtains approximate values for the equivalent dose to the skin. Similarly, $H_p(3)$ or $H'(3)$ may be used for an approximate assessment of the equivalent dose to the lens of the eye. Formal definitions of the operational quantities are given in the Glossary of the BSS, and a more detailed discussion can be found in Ref. [3].

2.45. The quantity of primary interest for internal dose is the intake. Intake is defined in the Glossary of the BSS as the process of taking radionuclides into the body by inhalation or ingestion or through the skin. In this instance, however, it is used to refer to the activity of the radionuclide taken into the body. The intake is normally determined from individual measurements, e.g. in vitro measurements of activity in samples, in vivo measurements (whole body, thorax, thyroid counting, etc.), or measurements using personal air sampling. In some cases, however, measurements of ‘exposure’ in terms of the time integrated air concentration may need to be determined by area monitoring. The intake of each radionuclide j is then multiplied by the appropriate dose coefficient (committed effective dose per unit intake) for ingestion $e(g)_{j,ing}$ or for inhalation $e(g)_{j,inh}$ [14], to determine the committed effective dose. Committed effective dose, $E(\tau)$, is defined in the Glossary of the BSS; τ is the time after an intake over which the dose is integrated. In the case of occupational exposure, only adults are exposed, and therefore τ is taken to be 50 years irrespective of the age at intake.

2.46. The total effective dose E_t received or committed during any time period t can be estimated from the following expression:

$$E_t = H_p(10) + \sum_j e(g)_{j,ing} I_{j,ing} + \sum_j e(g)_{j,inh} I_{j,inh}$$

where $H_p(10)$ is the personal dose equivalent at a depth of 10 mm in soft tissue during time period t , $e(g)_{j,ing}$ and $e(g)_{j,inh}$ are the dose coefficients for, respectively, ingestion and inhalation of radionuclide j by age group g , and $I_{j,ing}$ and $I_{j,inh}$ are the intakes, via ingestion and inhalation respectively, of radionuclide j during time period t . For occupational exposure, the appropriate values for $e(g)_{j,ing}$ and $e(g)_{j,inh}$ are those for

adult workers, given in Table II–III of the BSS (conversion coefficients for radon progeny are given in BSS Table II–II).

3. DOSE LIMITATION

DOSE LIMITS

3.1. A dose limit is defined in the BSS as “The value of the effective dose or the equivalent dose to individuals from controlled practices that shall not be exceeded.” The limits on effective dose for occupational exposure apply to the sum of effective doses from external sources and committed effective doses from intakes in the same period (Ref. [2], para. II-5):

“The occupational exposure of any worker shall be so controlled that the following limits be not exceeded:

- (a) an effective dose of 20 mSv per year averaged over five consecutive years³⁸;
- (b) an effective dose of 50 mSv in any single year;
- (c) an equivalent dose to the lens of the eye of 150 mSv in a year; and
- (d) an equivalent dose to the extremities (hands and feet) or the skin³⁹ of 500 mSv in a year.

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

³⁹ The equivalent dose limits for the skin apply to the average dose over 1 cm² of the most highly irradiated area of the skin. Skin dose also contributes to the effective dose, this contribution being the average dose to the entire skin multiplied by the tissue weighting factor for the skin.”

3.2. Separate limits are specified for apprentices of age 16–18 who are training for employment involving exposure to radiation, and for students of age 16–18 who need to use sources in the course of their studies (Ref. [2], para. II–6, with footnote 39 as above):

“The occupational exposure shall be so controlled that the following limits be not exceeded:

- (a) an effective dose of 6 mSv in a year;
- (b) an equivalent dose to the lens of the eye of 50 mSv in a year; and
- (c) an equivalent dose to the extremities or the skin³⁹ of 150 mSv in a year.”

3.3. Regulatory authorities should clearly define the convention to be followed in determining the periods to be used for dose limitation. Calendar or national fiscal years are simple examples that may be used for the single year periods. ‘Rolling’ five-year periods, in which the current single year (calendar, fiscal, etc.) is considered the final year in the five-year period, may be selected for averaging purposes. Alternative conventions may be adopted to meet national regulatory needs.

3.4. Cases where the flexibility provided by the averaging of doses over five years might be needed include planned maintenance operations in nuclear plants. However, in many situations, provided the principle of optimization of protection has been appropriately applied, it will be very unusual for workers to exceed an annual effective dose of 20 mSv. Where the flexibility provided by averaging is not needed, the regulatory authority may prefer to continue to operate with an annual limit; the dose limit would then be 20 mSv in a year.

3.5. The general approach to the application of the dose limits where full flexibility is used (i.e. averaging of doses over five years) can be summarized as follows:

- (a) In general, the effective dose to an individual worker should not exceed 20 mSv in a year;
- (b) Where doses to an individual worker exceed 20 mSv in a year but remain within the dose limit of 50 mSv, the management, as appropriate, should do the following:
 - (i) Carry out a review of exposure to determine whether doses were as low as reasonably achievable, and where appropriate take the necessary corrective steps;
 - (ii) Consider ways to restrict further effective doses to the individual worker so that the total effective dose to that worker, within the chosen five-year averaging period, is less than 100 mSv;
 - (iii) Notify the regulatory authority of the magnitude of the dose and the circumstances leading to the exposure.

3.6. Regulatory authorities are obliged by the BSS to require employers to report to them promptly when any of the dose limits is exceeded. Employers should therefore have systems in place to notify the regulatory authority, and the worker(s) involved in the event, that a dose limit has been exceeded (Ref. [2], paras. 1.11, 1.12 and 1.14):

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

.....

- (c) communicate to the Regulatory Authority, and to the relevant Sponsoring Organizations when applicable, on the causes of the breach and on the corrective or preventive actions taken or to be taken.”

“The communication of a breach of the Standards shall be prompt...”

.....

“Wilful breach of, attempted breach of or conspiracy to breach any requirement of the Standards shall be subject to the provisions for such infractions by the appropriate national legislation of the State, or by the Regulatory Authority...”

Regulatory authorities are therefore also obliged to establish the range of actions and penalties that may be taken against any employer who fails to take account of the requirement of the BSS in complying with the dose limits.

3.7. Situations in which workers exceed the single year limit of 50 mSv should be considered exceptional. These may occur as the consequence of an emergency, accident or intervention. In the event that a worker receives a single year exposure which exceeds 50 mSv, it would be appropriate for the worker to continue working with radiation provided that:

- (a) The regulatory authority, having due regard to the health of the worker, considers there is no reason to prevent continuing work with radiation;
- (b) The management and the regulatory authority, in consultation with the worker (through his or her representatives where appropriate), agree on a temporary dose restriction and the period to which it applies.

A restriction based pro rata on the remaining period of time to which the dose limit relates might be appropriate, and further restrictions may need to be applied in order to keep within the dose limit of 100 mSv in five years.

3.8. In general, the dose limits apply equally to male and female workers. However, because of the possibility of a greater sensitivity of the foetus to radiation, additional controls may have to be considered for pregnant workers. Special requirements for radiation protection of pregnant workers are addressed in paras 2.39, 5.33 and 5.98.

3.9. Regulatory authorities should ensure that systems are in place which prevent workers who have received an exposure close to a relevant dose limit being deprived of their right to work. Situations may arise in which a worker has unintentionally

TABLE I. LIMITS ON INTAKE AND EXPOSURE FOR RADON PROGENY AND THORON PROGENY

Time period	Quantity	Units	Radon progeny	Thoron progeny
Annual average over 5 years	Potential alpha energy intake	J	0.017	0.051
	Potential alpha energy exposure	J·h/m ³	0.014	0.042
		Bq·h/m ³	2.5×10^6 ^a	—
WLM		4.0	12	
Maximum in a single year	Potential alpha energy intake	J	0.042	0.127
	Potential alpha energy exposure	J·h/m ³	0.035	0.105
		Bq·h/m ³	6.3×10^6 ^a	—
WLM		10.0	30	

^a These time integrated activity concentrations relate to the equilibrium equivalent concentration of radon. The associated time integrated concentration of radon gas is obtained by dividing by the appropriate equilibrium factor.

received a total dose that is close to the relevant dose limit, such that further planned exposures may result in that limit being exceeded. This situation should be treated in a similar manner to that of a worker who exceeds a dose limit (see para. 3.7).

SPECIAL CIRCUMSTANCES

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

3.11. A temporary change to the dose limitation arrangements is permitted by the BSS, subject to a number of conditions, including prior approval by the regulatory authority. Procedures for varying dose limits in special circumstances are

recommended in paras I.50–I.54 (Appendix I) of the BSS, and two alternatives for a temporary change in the dose limitation requirements are specified in para. II–7 (Schedule II) of the BSS.

3.12. The need to make use of these conditions and procedures for special circumstances will have diminished with the passage of time and therefore the detailed requirements are not reproduced here.

LIMITS ON EXPOSURE FOR RADON PROGENY AND THORON PROGENY

3.13. The limits on intake and exposure for radon progeny and thoron progeny given in Schedule II of the BSS are summarized in Table I.

4. OPTIMIZATION OF RADIATION PROTECTION FOR PRACTICES

GENERAL

4.1. Optimization of protection needs to be considered at all stages of the life of equipment and installations, in relation to both normal and potential exposures. As a consequence, all situations — from design, through operation to decommissioning and waste management — should be considered in the optimization procedure.

4.2. From the practical viewpoint, the optimization principle calls for an approach that:

- (a) considers all possible actions involving the source(s) and the way workers operate with or near the source(s);
- (b) implies a ‘management by objective’ process with the following sequence: setting objectives, measuring performance, evaluating and analysing performance to define corrective actions, and setting new objectives;
- (c) can be adapted to take into account any significant change in the state of techniques, the protection resources available, or the prevailing social context;
- (d) encourages accountability, such that all parties adopt a responsible attitude to the process of eliminating unnecessary exposures.

4.3. The process of optimization should take account of:

- (a) The resources available for protection;
- (b) The distribution of individual and collective exposure among different groups of workers, and between workers and members of the public;
- (c) The probability and magnitude of potential exposure;
- (d) The potential impact of protection actions on the level of other (non-radiological) risks to workers or members of the public.

4.4. In general, the incremental benefits to be obtained in terms of dose reduction decrease progressively as the associated expenditure increases. Even the cost of considering the ways in which doses may be reduced can become significant compared with the benefit to be achieved. At some stage, for low doses, the effort may not be worthwhile. In this context, it is noted that the BSS allow for the exemption of practices from regulatory control when an assessment shows that exemption is the optimum protection option (BSS Schedule I). This provision is simply a recognition of the more general concept of diminishing returns.

4.5. The optimization of protection should be considered at the design stage of equipment and installations, when some degree of flexibility is still available. The use of engineered controls should be examined carefully at this stage in defining the protection options. Even if protection has been optimized at the design stage, however, there is still a need to implement the optimization principle during the operational phase. At this stage, the content and the scale of the optimization programme will depend on the exposure situation. For example, when dealing with X ray machines, the optimization programme can be quite straightforward, involving local rules and appropriate training of the operators. In the nuclear industry, situations may be more complicated, and a more structured approach may be needed, including the construction of detailed radiation protection programmes, the establishment of investigation levels and the use of decision aiding techniques (see paras 4.13–4.16).

4.6. Optimization of protection in operation is a process that begins at the planning stage and continues through the stages of scheduling, preparation, implementation and feedback. This process of optimization through work management is applied in order to keep exposure levels under review, to ensure that they are as low as reasonably achievable [15]. The elaboration of a radiation protection programme, adapted to the specific exposure situations, is an essential element of work management. The content of such a programme is described in Section 5.

4.7. Management should record information on the way in which they are implementing optimization of radiation protection. This information could include the following:

- (a) The rationale for proposed operating, maintenance and administrative procedures, together with other options that have been considered and the reason for their rejection;
- (b) Periodic review and trend analysis for occupational doses to various work groups, and other performance indicators;
- (c) Internal audits and peer reviews, and the resulting corrective actions;
- (d) Incident reports and lessons learned.

COMMITMENT TO OPTIMIZATION OF PROTECTION

4.8. The primary responsibility for optimization lies with the management. Commitment to an effective protection and safety policy is essential at all levels of management, particularly at the senior level. The management commitment should be demonstrated by written policy statements that make radiation protection criteria an integral part of the decision process, and by clear and demonstrable support for those persons with direct responsibility for radiation protection in the workplace and the environment.

4.9. Senior management should translate their commitment to optimization of radiation protection into effective action by establishing appropriate radiation protection programmes, commensurate with the level and the nature of the radiological risk presented by the practice. The content of such programmes is discussed in Section 5.

4.10. It is essential that workers also have a commitment to good radiation protection. Management must thus ensure that mechanisms are in place by which workers can be involved, as much as possible, in the development of methods to keep doses as low as reasonably achievable, and have the opportunity to provide feedback on the effectiveness of radiation protection measures.

4.11. Optimization of protection should be a regulatory requirement. Regulatory authorities should be committed to optimization of radiation protection and should encourage its application. Where necessary, they should undertake all relevant actions to enforce regulatory requirements on management to apply this principle.

4.12. Management should ensure that training programmes, with content and duration commensurate with and adapted to the functions and responsibilities of the staff concerned, should be provided for staff at all levels, including senior management. The staff of regulatory authorities should have the training necessary to ensure that optimization of protection is appropriately applied and enforced.

USE OF DECISION AIDING TECHNIQUES

4.13. As stated in the BSS (Ref. [2], para. 2.25):

“The process of optimization of protection and safety measures may range from intuitive qualitative analyses to quantitative analyses using decision aiding techniques, but shall be sufficient to take all relevant factors into account in a coherent way so as to contribute to achieving the following objectives:

- (a) to determine optimized protection and safety measures for the prevailing circumstances, with account taken of the available protection and safety options as well as the nature, magnitude and likelihood of exposures; and
- (b) to establish criteria, on the basis of the results of the optimization, for the restriction of the magnitudes of exposures and of their probabilities by means of measures for preventing accidents and mitigating their consequences.”

4.14. In most situations, a qualitative approach based on professional judgement will be sufficient to make decisions on the most favourable level of protection that can be achieved. In more complex situations, particularly those involving significant expenditure (for example, at the design stage of installations), the use of a more structured approach may be appropriate. Some of those situations may be quantifiable using cost–benefit analysis or other quantitative techniques. In other cases, however, it may not be possible to quantify all of the factors involved, or to express them in commensurate units. It may also be difficult to make the balance between collective and individual doses, and between worker and public doses, and to take account of broader social factors. For these situations, the use of qualitative decision aiding techniques such as multicriteria analysis may be useful in making the decision.

4.15. A more structured approach to the selection of appropriate protection measures should include the following steps, account being taken of both normal and potential exposures:

- (a) Identify all practicable protection options that might potentially reduce the occupational exposure;
- (b) Identify all relevant economic, social and radiological factors for the particular situation under review that distinguish between the identified options, e.g. collective dose, distribution of individual dose, impact on public exposure, impact on future generations, investment costs;
- (c) Quantify, where possible, the relevant factors for each protection option;
- (d) Compare all options and select the optimal option(s);

- (e) When appropriate, perform a sensitivity analysis, i.e. evaluate the robustness of the solutions obtained, by testing different values for the key parameters for which recognized uncertainties exist.

4.16. Whatever the situation, decision makers must keep in mind that decision aiding techniques do not necessarily provide the definitive answer, nor the only possible solution. These techniques must be seen as tools to help structure problems in order to compare the relative effectiveness of various possible protection options, to facilitate the integration of all relevant factors and to improve the coherence of decisions taken.

ROLE OF DOSE CONSTRAINTS

4.17. The BSS definition [Ref. [2], Glossary] of ‘dose constraint’ states: “For occupational exposures, dose constraint is a source related value of individual dose used to limit the range of options considered in the process of optimization.” A dose constraint should not be regarded as a limit, but as a minimum level of individual protection that should be achieved in a particular situation, with due regard for all the circumstances. Discussion of the nature of dose constraints is provided in a joint document by the OECD/NEA and the European Commission [16].

4.18. The objective of a dose constraint is to place a ceiling on values of individual dose — from a source, a set of sources in an installation, a practice, a task or a group of operations in a specific type of industry — that could be considered acceptable in the process of optimization of protection for those sources, practices or tasks. Depending on the situation, the constraint can be expressed as a single dose or as a dose over a given time period. It is necessary to ensure that the limits are observed if workers incur exposures from different sources or tasks.

4.19. To apply the optimization principle, individual doses should be assessed at the design and planning stages, and it is these predicted individual doses for the various options that should be compared with the appropriate dose constraint. Options predicted to give doses below the dose constraint should be considered further; those predicted to give doses above the dose constraint would normally be rejected. Dose constraints should not be used retrospectively to check compliance with protection requirements.

4.20. Dose constraints should be used prospectively in optimizing radiation protection in various situations encountered in planning and executing tasks, and in designing facilities or equipment. They should therefore be set on a case-by-case

basis according to the specific characteristics of the exposure situation. Since dose constraints are source related, the source to which they relate should be specified. Dose constraints may be set by management, in consultation with those involved in the exposure situation. Regulatory authorities may use them in a generic way — for categories of similar sources, practices or tasks — or specifically, in licensing individual sources, practices or tasks. The establishment of constraints may be the result of interaction between the regulatory authority, the affected operators and, where appropriate, workers' representatives. As a general rule, it would be more appropriate for the regulator to encourage the development of constraints for occupational exposure within particular industries and organizational groupings, subject to regulatory oversight, than to stipulate specific values of constraints.

4.21. The process of deriving a dose constraint for any specific situation should include a review of operating experience and feedback from similar situations if possible, and considerations of economic, social and technical factors. For occupational exposure, the experience with well managed operations is of particular importance in setting constraints, as it should be for implementing the optimization principle in general. National surveys or international databases, delivering a large amount of experience with exposures related to specific operations, can be used in setting constraints.

ROLE OF INVESTIGATION LEVELS

4.22. Experience with a particular situation sometimes indicates a need to review procedures and performance. This experience may be qualitative (e.g. the observation that the frequency of occurrence of minor contamination may have increased) or quantitative (e.g. a trend in the results of monitoring programmes). The use of quantitative experience can be assisted by the application of investigation levels to monitoring results for individuals and workplaces. Investigation levels are one type of reference level (see Section 2). They are to be used in a retrospective sense, and should not therefore be confused with dose constraints. If an investigation level is exceeded, then this should prompt a review of the situation to determine the causes. This review should have the objectives of extracting appropriate lessons for any future operations and determining whether additional measures are needed to improve the current protection arrangements.

4.23. Investigation levels should be seen as important tools for use by management and should therefore be defined by management at the planning stage of activities; they may be revised on the basis of operational experience. Regulatory authorities may also wish to establish generic investigation levels in terms of individual dose for

regulatory purposes. Their use in radiation protection programmes is discussed more fully in Section 5.

5. RADIATION PROTECTION PROGRAMMES

OBJECTIVES

5.1. A radiation protection programme (RPP) may relate to all phases of a practice, or to the lifetime of a facility, i.e. from design through process control to decommissioning. Emphasis is given in this section to the operational aspects of the RPP. The general objective of RPPs is to reflect the application of the management responsibility for radiation protection and safety through the adoption of management structures, policies, procedures and organizational arrangements that are commensurate with the nature and extent of the risks.

5.2. Although the RPP may include protection of both workers and the public, this section focuses only on those aspects dealing with the protection of workers. In most practices, doses received by workers are well below the appropriate limits in the BSS, and only a small fraction of the workforce will be affected by the limitation principle. Implementation of the optimization principle should be the principal driving force behind the establishment and implementation of RPPs, including in many cases measures to prevent or reduce potential exposures and to mitigate the consequences of accidents.

5.3. The characteristics of exposure situations may vary considerably depending on the type of installation concerned (ranging from 'simple' ones, such as baggage inspection equipment in airports, to much more complex ones, such as nuclear reprocessing plants), and on the stage of activities (construction, operation, maintenance or decommissioning). It is important to ensure that the RPP is well adapted to the situation. Therefore, the first step towards the definition of an RPP is to perform a prior radiological evaluation of the practice or installation. In these evaluations, both normal and potential exposures need to be considered.

PRIOR RADIOLOGICAL EVALUATION AND SAFETY ASSESSMENT

5.4. The purpose of the prior radiological evaluation is to describe, as precisely as necessary, the situation involving occupational exposures, as a first step in the

development of an RPP. The level of effort, formality and detail of the evaluation, and the scrutiny to which it is subjected, must be linked to the magnitude of the routine and potential exposures and the probabilities of these potential exposures.

5.5. The prior radiological evaluation should include, for all aspects of operations:

- (a) an identification of the sources of routine and reasonably foreseeable potential exposures;
- (b) a realistic estimate of the relevant doses and probabilities;
- (c) an identification of the radiological protection measures needed to meet the optimization principle.

5.6. Prior evaluation will help to determine what can be achieved at the design stage to establish satisfactory working conditions through the use of engineered features. Examples would be the provision of shielding, containment, ventilation or interlocks. These considerations should aim to “minimize the need for relying on administrative controls and personal protective equipment for protection and safety during normal operations” (Ref. [2], para. I.29). Subsequent consideration may then be given to additional operational procedures and restrictions that might be implemented to further control the workers’ exposure. Only if these measures are not sufficient to adequately restrict the dose to workers will prior evaluation go on to consider the use of special tools, personal protective equipment and specific task related training.

5.7. Where authorization by registration or licensing is required, para. 2.13 of Ref. [2] requires the legal person applying for the authorization to make an assessment of the nature, magnitude and likelihood of the exposures and, if necessary, to make a safety assessment. Such a safety assessment should contribute to the design of the RPP. Paragraphs IV.4–IV.6 of the BSS (Ref. [2]) state that:

“The safety assessment shall include, as appropriate, a systematic critical review of:

- (a) the nature and magnitude of potential exposures and the likelihood of their occurrence;
- (b) the limits and technical conditions for operation of the source;
- (c) the ways in which structures, systems, components and procedures related to radiation protection or safety might fail, singly or in combination, or otherwise lead to potential exposures, and the consequences of such failures;
- (d) the ways in which changes in the environment could affect protection or safety;
- (e) the ways in which operating procedures related to protection or safety might be erroneous, and the consequences of such errors; and
- (f) the protection and safety implications of any proposed modifications.”

5.8. “The registrant or licensee shall, as appropriate, take into account in the safety assessment:

- (a) factors which could precipitate a substantial release of any radioactive substance and the measures available to prevent or control such a release, and the maximum activity of any radioactive substance which, in the event of a major failure of the containment, might be released to the atmosphere;
- (b) factors which could precipitate a smaller but continuing release of any radioactive substance and the measures available to prevent or control such a release;
- (c) factors which could give rise to the unintended operation of any radiation beam and the measures available to prevent, identify and control such occurrences;
- (d) the extent to which redundant and diverse safety features, being independent of each other so that failure of one does not result in failure of any other, are appropriate in order to restrict the probability and magnitude of potential exposures.”

5.9. “The safety assessment shall be documented and, if appropriate, independently reviewed within the relevant quality assurance programme. Additional reviews shall be performed as necessary for ensuring that the technical specifications or conditions of use continue to be met whenever:

- (a) significant modifications to a source or its associated plant or its operating or maintenance procedures are envisaged;
- (b) operating experience, or other information about accidents, failures, errors or other events that could lead to potential exposures indicates that the current assessment might be invalid; and
- (c) any significant changes in activities, or any relevant changes in guidelines or standards, are envisaged or have been made.”

SCOPE AND STRUCTURE OF THE RADIOLOGICAL PROTECTION PROGRAMME

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

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

- (a) The assignment of responsibilities for occupational radiation protection and safety to different management levels, including corresponding organizational arrangements and, if applicable (for example, in the case of itinerant workers), the allocation of the respective responsibilities between employers and the registrant or licensee;
- (b) The designation of controlled or supervised areas;
- (c) The local rules for workers to follow and the supervision of work;
- (d) The arrangements for monitoring workers and the workplace, including the acquisition and maintenance of radiation protection instruments;
- (e) The system for recording and reporting all the relevant information related to the control of exposures, the decisions regarding measures for occupational radiation protection and safety, and the monitoring of individuals;
- (f) The education and training programme on the nature of the hazards, protection and safety;
- (g) The methods for periodically reviewing and auditing the performance of the RPP;
- (h) The plans to be implemented in the event of intervention (discussed in Section 6);
- (i) The health surveillance programme (discussed in Section 7);
- (j) The requirements for the assurance of quality and process improvement, as described in paras 5.101–5.111.

ASSIGNMENT OF RESPONSIBILITIES

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

Officers should be appointed, when required by the regulatory authority, to oversee the application of the regulatory requirements.

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

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

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

Accountability for radioactive sources

5.16. The BSS (Ref. [2], para. IV.17) state that:

“Registrants and licensees shall maintain an accountability system that includes records of:

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

In addition, consideration needs to be given to keeping records on any special instructions for each radioactive substance held and details of the disposal of any source.

CLASSIFICATION OF AREAS

5.17. Management should consider classifying working areas whenever there is occupational exposure to radiation. These areas should be clearly defined as part of the RPP, and their classification should result from the prior radiological evaluation referred to above. Two types of area may be defined: controlled areas and supervised areas.

Controlled areas

5.18. The BSS (Ref. [2], para. I.21) state that:

“Registrants and licensees shall designate as a controlled area any area in which specific protective measures or safety provisions are or could be required for:

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

5.19. The BSS (Ref. [2], para. I.22) state that:

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

5.20. In particular, an area should be designated as a controlled area when management considers that there is a need to adopt procedural controls to ensure an optimized level of protection and compliance with the relevant dose limits. The designations are best based on operational experience and judgement. In areas where there is no problem of contamination by unsealed radioactive materials, designated areas may sometimes be defined in terms of the dose rate at the boundary. Values of dose rate based on a fraction of the relevant dose limit have often been used in the past for defining the boundaries of controlled areas. Such an approach may still be appropriate, but it should not be used without careful evaluation. For instance, account should be taken of the length of time for which the dose rate remains at or above the defined level and the risk from potential exposures.

5.21. Work with unsealed radioactive sources can result in contamination of the air and surfaces, and this in turn can lead to intakes of radioactive material by the

workers. Such contamination will generally be of an intermittent nature, and it will not normally be possible to control intakes by placing reliance solely on design features, particularly in the event of an accident or incident. Operational procedures will therefore be necessary to prevent or reduce the possibility of intake, and controlled areas will, in general, need to be established.

5.22. Controlled areas may not, however, need to be set up where only very small quantities of unsealed radioactive material are used, e.g. for tracer studies in a research laboratory. They may also be unnecessary when only materials with low activity concentrations of naturally occurring radionuclides (see para. 2.27) are handled.

5.23. The BSS (Ref. [2], para. I.23) state that:

“Registrants and licensees shall:

- (a) delineate controlled areas by physical means or, where this is not reasonably practicable, by some other suitable means;
- (b) where a source is brought into operation or energized only intermittently or is moved from place to place, delineate an appropriate controlled area by means that are appropriate under the prevailing circumstances and specify exposure times;
- (c) display a warning symbol, such as that recommended by the International Organization for Standardization (ISO)¹² and appropriate instructions at access points and other appropriate locations within controlled areas;
- (d) establish occupational protection and safety measures, including local rules and procedures that are appropriate for controlled areas;
- (e) restrict access to controlled areas by means of administrative procedures, such as the use of work permits, and by physical barriers, which could include locks or interlocks; the degree of restriction being commensurate with the magnitude and likelihood of the expected exposures;
- (f) provide, as appropriate, at entrances to controlled areas:
 - (i) protective clothing and equipment;
 - (ii) monitoring equipment; and
 - (iii) suitable storage for personal clothing;
- (g) provide, as appropriate, at exits from controlled areas:
 - (i) equipment for monitoring for contamination of skin and clothing;
 - (ii) equipment for monitoring for contamination of any object or substance being removed from the area;
 - (iii) washing or showering facilities; and
 - (iv) suitable storage for contaminated protective clothing and equipment; and

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

¹² INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Basic Ionizing Radiation Symbol, ISO 361, ISO, Geneva (1975).”

5.24. The signs at the entrances to controlled areas should be used to indicate to employees, especially maintenance staff, that special procedures apply in the area and that radiation sources are likely to be present.

5.25. In setting up controlled areas, management may find it useful to make use of existing physical boundaries, such as the walls of rooms or buildings. This may mean that the areas will be larger than would be strictly necessary on the basis of radiation protection considerations alone.

Supervised areas

5.26. The BSS (Ref. [2], para. I.24) state that:

“Registrants and licensees shall designate as a supervised area any area not already designated as a controlled area but where occupational exposure conditions need to be kept under review even though specific protection measures and safety provisions are not normally needed.”

5.27. The BSS (Ref. [2], para. I.25) state that:

“Registrants and licensees shall, taking into account the nature and extent of radiation hazards in the supervised areas:

- (a) delineate the supervised areas by appropriate means;
- (b) display approved signs at appropriate access points to supervised areas; and
- (c) periodically review the conditions to determine any need for protective measures and safety provisions or changes to the boundaries of supervised areas.”

5.28. Thus, the essential purpose of a supervised area is to identify those parts of the workplace that should be subject to regular review of the radiological conditions to determine whether the status of the area should be changed — as a result, for example, of circumstances that were not foreseen in the prior radiological evaluation — or whether there has been some breakdown of control, either in the design features or in the procedures that operate in any adjacent controlled area. Normally, the review

of the radiological conditions would comprise a programme of regular monitoring of the area and, in some cases, of the individuals who work within it. It should not automatically be necessary to set up a supervised area around every controlled area, as the requirements that apply within a designated controlled area may well be sufficient.

5.29. As with controlled areas, the definitions of supervised areas are best based on operational experience and judgement but, again, use may be made of a dose rate to define the boundary. A reasonable objective would be to ensure that those workers exposed outside designated areas should receive the same level of protection as if they were members of the public. This would imply the use of a dose rate based on an effective dose of 1 mSv in a year as one possible means of defining the outer boundary of a supervised area. Furthermore, as with controlled areas, it may be appropriate to make use of existing physical boundaries when defining supervised areas (see para. 5.25).

5.30. Although it may be appropriate in many cases for the boundaries of supervised areas to be marked with signs, this may not always be necessary or productive. For example, it may be necessary to designate supervised areas in parts of hospitals to which members of the public may have access; signs at the entrances to such areas may cause unnecessary concern.

5.31. The conditions in supervised areas should be such that employees are able to enter with a minimum number of formalities.

LOCAL RULES, SUPERVISION AND PERSONAL PROTECTIVE EQUIPMENT

5.32. Local rules, describing the organizational structures and the procedures to be followed in controlled areas, should be developed by management and written down. The rules should be prominently displayed or readily available in the workplace. Specifically (Ref. [2], paras I.26 and I.27):

“Employers, registrants and licensees shall, in consultation with workers, through their representatives if appropriate:

- (a) establish in writing such local rules and procedures as are necessary to ensure adequate levels of protection and safety for workers and other persons;
- (b) include in the local rules and procedures the values of any relevant investigation level or authorized level, and the procedure to be followed in the event that any such value is exceeded;

- (c) make the local rules and procedures and the protective measures and safety provisions known to those workers to whom they apply and to other persons who may be affected by them;
- (d) ensure that any work involving occupational exposure be adequately supervised and take all reasonable steps to ensure that the rules, procedures, protective measures and safety provisions be observed; and
- (e) when required by the Regulatory Authority, designate a radiation protection officer.”

5.33. “Employers, in co-operation with registrants and licensees, shall:

- (a) provide to all workers adequate information on the health risks due to their occupational exposure, whether normal exposure or potential exposure, adequate instruction and training on protection and safety, and adequate information on the significance for protection and safety of their actions;
- (b) provide to female workers who are liable to enter controlled areas or supervised areas appropriate information on:
 - (i) the risk to the embryo or foetus due to exposure of a pregnant woman;
 - (ii) the importance for a female worker of notifying her employer as soon as she suspects that she is pregnant; and
 - (iii) the risk to an infant ingesting radioactive substances by breast feeding;
- (c) provide to those workers who could be affected by an emergency plan appropriate information, instruction and training; and
- (d) keep records of the training provided to individual workers.”

5.34. Management should assign responsibility for the supervision of tasks. This supervision should be exercised to ensure that all the required protection and safety measures have been followed during work.

5.35. When engineered and operational controls are not sufficient to provide an optimized level of protection for the tasks to be performed, personal protective equipment should be used. When exposure reduction measures using protective equipment are being considered, account should be taken of any possible increased exposure due to delays or inconveniences caused by the use of the equipment (Ref. [2], para. I.28):

“Employers, registrants and licensees shall ensure that:

- (a) workers be provided with suitable and adequate personal protective equipment which meets any relevant standards or specifications, including as appropriate:
 - (i) protective clothing;

- (ii) protective respiratory equipment for which the protection characteristics are made known to the users; and
 - (iii) protective aprons and gloves and organ shields;
- (b) when appropriate, workers receive adequate instruction in the proper use of respiratory protective equipment, including testing for good fit;
 - (c) tasks requiring the use of some specific personal protective equipment be assigned only to workers who on the basis of medical advice are capable of safely sustaining the extra effort necessary;
 - (d) all personal protective equipment be maintained in proper condition and if appropriate be tested at regular intervals;
 - (e) appropriate personal protective equipment be maintained for use in the event of intervention; and
 - (f) if the use of personal protective equipment is considered for any given task, account be taken of any additional exposure that could result owing to the additional time or inconvenience, and of any additional non-radiological risks that might be associated with performing the task while using protective equipment.”

WORK PLANNING AND RADIATION WORK PERMITS

5.36. When an operation is to be conducted during which significant radiation or contamination levels may be encountered, or implementation of which may be complex (involving several working groups and numerous activities), advance work planning is one of the most important means of achieving optimization of protection. The Radiation Protection Officer should take part in the planning of activities involving significant exposures, and should advise on the conditions under which work can be undertaken in controlled areas. The situations which warrant the use of detailed work plans and work permits are generally encountered in the nuclear industry, but may also be found in non-nuclear industries (e.g. in the maintenance or dismantling of accelerators). Additional guidance on the use of work planning for optimization has been published by the OECD/NEA [15].

5.37. Written procedures should be used as part of the work planning process as appropriate. Elements to be considered include:

- (a) Information from similar work completed previously;
- (b) Time for starting the work, its estimated duration, and the human resources involved;

- (c) Maps of estimated dose rates;
- (d) Operation state of the plant (e.g. for a nuclear power plant, cold or hot shutdown, operation at full or decreased power);
- (e) Other activities in the same area which may interfere with the work;
- (f) Preparation and assistance in operations (isolation of the process, scaffolding, insulation work, etc.);
- (g) Protective clothing and tools to be used;
- (h) Communication necessary to ensure supervisory control and co-ordination;
- (i) Handling of waste arising;
- (j) Conventional safety.

5.38. For each task that needs radiological precautions to be taken, a Radiation Work Permit (RWP) should normally be prepared. The RWP is issued by the persons in charge of the planning of the operations, in collaboration with the Radiation Protection Officer. A copy of the RWP should be provided to the supervisor of the work and should remain with the working team during the performance of the work. In addition to a description of the work to be performed, the RWP may include:

- (a) A detailed dose rate map of the working area and possible hot spots, produced from a survey made prior to the work or otherwise estimated;
- (b) An estimate of contamination levels and how they may change during the course of the work;
- (c) An estimate of individual and collective exposure for each work step;
- (d) Specification of any additional dosimeters to be used by the workers;
- (e) Specification of protective equipment to be used in different phases of the work;
- (f) Details of any time or dose restrictions;
- (g) Instructions on when to contact the Radiation Protection Officer.

MONITORING AND DOSE ASSESSMENT

5.39. Measurements related to the assessment or control of exposure to radiation and radioactive materials are described by the general term ‘monitoring’. Although measurements play a major part in any RPP, monitoring is more than simply measurement; it requires interpretation and assessment. The primary justification for measurement must therefore be found in the way in which it helps to achieve and demonstrate adequate protection, including implementation of optimization of protection. The main functions of the various forms of monitoring are discussed in this section. More guidance is given in the companion Safety Guides on dose assessment [3, 4].

5.40. Monitoring may provide important supplementary benefits in the fields of industrial or public relations — such as reassurance and motivation of the workforce — or of scientific investigation — such as data for epidemiological studies — or in providing information useful in the determination of liability in the event of the expression of adverse health effects in individual workers. These considerations may well affect decisions about the nature and extent of monitoring programmes, but they do not in themselves provide the primary justification for a monitoring programme for radiological protection. Despite its importance, monitoring is a technique for radiological protection; it is not an end in itself.

5.41. Thus, a programme of monitoring may be used for a number of specific purposes, depending on the nature and extent of the practice. These purposes may include:

- (a) Confirmation of good working practices (e.g. the adequacy of supervision and training) and engineering standards;
- (b) Provision of information about conditions in the workplace and means of establishing whether these are under satisfactory control and whether operational changes have improved or worsened the radiological working conditions;
- (c) Estimation of the actual exposure of workers, to demonstrate compliance with regulatory requirements;
- (d) Evaluation and development of operating procedures from review of collected monitoring data for individuals and groups (such data may be used to identify both good and bad features of operating procedures and design characteristics, and thereby contribute to the development of safer radiation working practices);
- (e) Provision of information that can be used to allow workers to understand how, when and where they are exposed and to motivate them to reduce their exposure;
- (f) Provision of information for the evaluation of doses in the event of accidental exposures.

Furthermore, monitoring data may also be used:

- (g) For risk–benefit analysis;
- (h) To supplement medical records;
- (i) For epidemiological studies of the exposed population.

5.42. The principal responsibility for setting up a monitoring programme rests with the management. The monitoring programme should therefore be designed by the management, on the basis of the prior radiological evaluation discussed in paras 5.4–5.6, with due account being taken of regulatory requirements.

5.43. Monitoring programmes can be divided and subdivided into a number of different types. The first division relates to the objectives of the monitoring. At this level, three types of monitoring are conducted for radiation protection purposes:

- (a) Routine monitoring is associated with continuing operations and is intended to demonstrate that the working conditions, including the levels of individual dose, remain satisfactory, and to meet regulatory requirements. It is thus largely confirmatory in nature, but underpins the overall operational monitoring programme.
- (b) Task related monitoring applies to a specific operation. It provides data to support the immediate decisions on the management of the operation. It may also support the optimization of protection.
- (c) Special monitoring is investigative in nature and typically covers a situation in the workplace for which insufficient information is available to demonstrate adequate control. It is intended to provide detailed information to elucidate any problems and to define future procedures. It should normally be undertaken at the commissioning stage of new facilities, following major modifications either to facilities or procedures, or when operations are being carried out under abnormal circumstances such as an accident.

5.44. Each of these types can be subdivided on the basis of the location of monitoring:

- (a) Workplace monitoring comprises measurements made in the working environment;
- (b) Individual monitoring is taken to mean measurement by equipment worn by individual workers, or measurement of quantities of radioactive materials in or on their bodies, and the interpretation of such measurements.

5.45. Workplace monitoring can be further subdivided into monitoring for external radiation, air contamination and surface contamination. Individual monitoring can be further subdivided into monitoring for external exposure, internal exposure and skin contamination. The details of the programmes will be influenced by the type and energy of the radiation and the radionuclides involved.

5.46. The design and implementation of a monitoring programme should conform to quality assurance requirements, to ensure that procedures are established and followed correctly, and that records are promptly made and correctly maintained. The equipment to be used in the monitoring programme should be suitable for the radiation type(s) and the form(s) of radioactive material encountered in the

workplace. The equipment should be calibrated to meet appropriate standards. More detailed guidance is presented in related IAEA/ILO documents [3, 4, 17].

5.47. The objectives of a monitoring programme should be clearly defined and recorded, and the programme design should reflect these objectives. The design should include the basis for the interpretation of the monitoring results and how this is related to the objectives of the programme, and this basis should be recorded. Distinction should also be made in the programme between monitoring for the purpose of controlling operations and monitoring for the formal assessment of dose to meet regulatory requirements.

5.48. The monitoring programme design should indicate the records that need to be kept and the associated record keeping and record disposal procedures. All these aspects should be reviewed regularly, at intervals determined by management, or following any major change in operations of the installation or in regulatory requirements. The purpose of such reviews should be to ensure that the monitoring effort (type, frequency and extent) is appropriately employed. The information should also be used to identify both good and bad features of operating procedures and design characteristics.

Individual monitoring

5.49. The BSS (Ref. [2], para. I.33) state that:

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

Examples of situations where individual monitoring may be inappropriate or not feasible are presented in the Safety Guides on exposure assessment [3, 4].

5.50. The BSS (Ref. [2], para. I.34) state that:

“For any worker who is regularly employed in a supervised area or who enters a controlled area only occasionally, individual monitoring shall not be required but the occupational exposure of the worker shall be assessed. This assessment shall be on the basis of the results of monitoring of the workplace or individual monitoring.”

5.51. The BSS (Ref. [2], para. I.35) state that:

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

5.52. External exposure to strongly penetrating photon radiation can normally be readily assessed by individual monitoring. Assessment of individual exposure to other radiation qualities (e.g. low energy X rays, neutrons and beta particles) is more difficult. A dosimeter should be able to measure the operational quantities for the particular type of radiation present. Where practicable, dosimeters to be used for routine monitoring should be designed to measure the maximum reasonably foreseeable potential exposure, as determined in the prior evaluation. Where this is not practicable, suitable alternative arrangements, such as area monitors or additional dosimeters, should be provided. For non-uniform exposure, it may be necessary on occasions to wear additional dosimeters for parts of the body (e.g. hands or fingers) which appear likely to receive a significant fraction of the dose limit applicable to that part of the body.

5.53. Where significant exposures are likely to accrue within the normal assessment interval of a routine dosimeter, or where radiological conditions may be expected to change significantly during work, additional dosimeters may well be useful. In these situations, direct reading dosimeters have particular advantages because they can be read by the user during the work process and records of exposure can be made on completion of work periods or phases.

5.54. The BSS (Ref. [2], para. I.36) state that:

“Employers shall ensure that workers who may be exposed to radioactive contamination, including workers who use protective respiratory equipment, be identified and shall arrange for appropriate monitoring to the extent necessary to demonstrate the effectiveness of the protection provided and to assess the intake of radioactive substances or the committed doses, as appropriate.”

5.55. Individual monitoring for internal dose assessment should be used when the internal dose may be significant. Wherever possible, the intake of radioactive material should be assessed using *in vivo* or *in vitro* measurements, or by monitoring with personal air samplers. The major technical factors that should influence the decision to undertake routine individual monitoring for internal radiation are the expected levels and likely variations of the intakes, and the complexity of the measurement and interpretation procedures comprising the monitoring programme. More detailed guidance on internal dose assessment is provided in the related Safety Guide [4].

5.56. To secure the necessary accuracy and precision, individual dosimetry should be performed, whenever possible, by an approved dosimetry service. The regulatory authority should give consideration to the establishment of a national accreditation procedure as a basis for the approval of dosimetry services.

Workplace monitoring

5.57. The BSS (Ref. [2], para. I.37) state that:

“Registrants and licensees, in co-operation with employers if appropriate, shall establish, maintain and keep under review a programme for the monitoring of the workplace under the supervision, if so required by a Regulatory Authority, of a qualified expert and a radiation protection officer.”

5.58. The BSS (Ref. [2], para. I.38) state that:

“The nature and frequency of monitoring of workplaces shall:

- (a) be sufficient to enable:
 - (i) evaluation of the radiological conditions in all workplaces;
 - (ii) exposure assessment in controlled areas and supervised areas; and
 - (iii) review of the classification of controlled and supervised areas; and
- (b) depend on the levels of ambient dose equivalent and activity concentration, including their expected fluctuations and the likelihood and magnitude of potential exposures.”

5.59. The BSS (Ref. [2], para. I.39) state that:

“The programmes for monitoring of the workplace shall specify:

- (a) the quantities to be measured;
- (b) where and when the measurements are to be made and at what frequency;
- (c) the most appropriate measurement methods and procedures; and
- (d) reference levels and the actions to be taken if they are exceeded.”

5.60. The results and findings of workplace monitoring should be recorded (see para. 5.86), and made available to line management and employees (through their representatives if appropriate). This information should be used in support of pre- and post-job evaluations, job planning, contamination control and management of radiological control operations. Significant changes in monitoring results should be

identified and trends analysed periodically. Corrective actions should be taken as necessary.

5.61. Particular attention should be given to the selection and use of instruments to ensure that their performance characteristics are appropriate for the specific workplace monitoring situation. Guidance on considerations related to the acquisition, use, maintenance and testing of radiation protection instruments may be found in the related Safety Guides [3, 4] and a Safety Report which addresses the calibration of instruments and dosimeters [17].

Individual dose assessment

5.62. The BSS (Ref. [2], para. I.32) state that:

“The employer of any worker, as well as self-employed individuals, and the registrants and licensees shall be responsible for arranging for the assessment of the occupational exposure of workers, on the basis of individual monitoring where appropriate, and shall ensure that adequate arrangements be made with appropriate dosimetry services under an adequate quality assurance programme.”

Quality assurance requirements that should apply to dosimetry services are discussed in the related Safety Guides on occupational exposure assessment [3, 4].

5.63. The decision to employ individual monitoring may be influenced by the expected levels and likely variations in the doses or intakes, and the complexity of the measurement and interpretation procedures comprising the measurement programme. Individual dose assessment uses the results from both individual and workplace measurements to assign a value of external or internal exposure to an individual or to a group of individuals.

5.64. Formal dose assessment means the determination of individual dose — undertaken within a well defined quality assurance framework — subject to the guidance and approval of the regulatory authority. Formal dose assessment should be required for any worker who is normally employed in a controlled area. For any single component of occupational exposure (e.g. strongly penetrating photon radiation, neutron irradiation, internal exposure), such assessments should be considered if monitoring indicates that the corresponding annual effective dose exceeds 1 mSv, and should certainly be conducted for total annual effective doses estimated to be above 5 mSv. Consideration should also be given to the likelihood and possible magnitude of potential exposures.

5.65. Monitoring of exposure, without necessarily the need for formal dose assessment, should be undertaken for any worker regularly employed in a supervised area, or who occasionally enters a controlled area, but whose doses are not expected to be significant. This monitoring may be based on the results of regular workplace measurement programmes.

5.66. In general, an individual worker's radiation exposure should be assessed from the results of individual monitoring. There are occasions, particularly in the assessment of internal doses, when this may not be feasible or practicable and reliance has to be placed on workplace monitoring. Where this is so, the monitoring programme should provide detailed information on the worker's movements, and the temporal and spatial variations in air concentrations in the worker's immediate environment.

5.67. To assess individual exposure to internal radiation, a level of intake or air concentration may need to be established to be used as an indication that there is a potential for a significant individual dose. In the derivation of such a level, the particular radioactive substances and exposure pathways of the relevant workplace should be taken into account if possible. If the level is exceeded, additional direct measurements of the individual's internal exposure may be necessary. This may also be desirable if there is any doubt whether the accuracy of the assessed dose for the specific workplace conditions is acceptable.

5.68. For dose assessments, it is important to evaluate the accuracy of the particular monitoring procedures or devices used to determine external and internal exposure. The objective should be to establish as comprehensive a record as is reasonable of credible formally assessed doses. Management should take account of the factors affecting the accuracy of dose assessment, define the accuracy criteria for formal dosimetry and dose assessment procedures, and take reasonable and appropriate measures to quantify and minimize uncertainties.

5.69. For visitors making short and infrequent visits to controlled areas, such that there is no likelihood of any significant exposures, individual monitoring and record keeping is unnecessary. However, knowledge of the radiological conditions in the areas visited — for example data from area monitoring or from individual monitoring of the visitors' escort — is necessary and should be recorded.

Use of investigation levels

5.70. Investigation levels (see para. 2.14) have an important role to play in monitoring programmes. Regulatory authorities may also wish, for regulatory

purposes, to establish a generic investigation level in terms of individual exposure. Investigation levels can be set in terms of virtually any measurable quantity related to the individual or the working environment. They should be defined by management in their RPP, their purpose being to facilitate the control of operations and exposures. If they are exceeded, a review should be initiated to address the protection and safety arrangements and the reasons for the value being exceeded. Such reviews may lead to the introduction of additional protection and safety measures.

5.71. Investigation levels for individual dose and intake should be set by management on the basis of expected individual dose levels. Values based on a selected fraction of the relevant dose limit, and corresponding to the period of time to which the individual result refers, may be of benefit to the regulatory authority. In the past, investigation levels were often based on three-tenths of the dose limit. This may still be acceptable in some situations.

5.72. Workplace monitoring may involve measurement of dose rates, contamination levels and airborne radioactive materials, or a combination thereof. Investigation levels for workplace monitoring should be set by management on the basis of the expected levels and operational experience. Frequently, some fraction of the derived air concentration (DAC) is used as a means of indicating the significance of a particular measurement of air concentration. Values of surface contamination (activity per unit area) derived from a fraction of the relevant dose limit have also been useful in indicating the significance of particular measurements. Such values often play the role of investigation levels, and may be useful in indicating a deterioration in radiological working conditions.

5.73. Investigation levels should be defined at the planning stage of activities, and may be revised when necessary on the basis of operational experience. A level may be set for individuals involved in a particular operation, or be derived specifically for individuals within a place of work without reference to a particular operation. The latter are particularly relevant when individuals are exposed to a number of different sources in a workplace or are involved in a number of different tasks at work.

5.74. Management should identify those responsible for initiating investigations when they are required. The purpose of, and the actions associated with, each investigation level should be clearly defined in advance. The investigation should address:

- (a) The circumstances leading to the suspected exposure;
- (b) Verification of the dosimetric results;

- (c) The probability that dose limits or levels will be exceeded under current working conditions;
- (d) The corrective actions to be taken.

Records

Occupational exposure assessment records

5.75. The BSS require that “Employers, registrants and licensees shall maintain exposure records for each worker for whom assessment of occupational exposure is required” (Ref. [2], para. I.44). It follows that each facility should establish a procedure that indicates how monitoring data and results are to be reported, what dose levels are to be recorded and what documents and records of radiation exposure should be maintained. In general, the dosimetry service has limited direct contact with workers and facility management. Monitoring results are, however, often used by management to advise operational radiation protection personnel when worker intervention, such as follow-up sampling or work restriction, is necessary. Consequently, close co-operation is needed between those involved in different parts of the monitoring and protection programmes.

5.76. Dose record keeping is the making and keeping of individual dose records for radiation workers. Record keeping is an essential part of the individual monitoring process.

5.77. The monitoring programme should have defined appropriate dose assessment or monitoring periods, related to dosimeter processing or a sampling programme. Dose records for individuals should be constructed so that the assessed doses for these periods are separately identifiable.

5.78. Dose records should be kept up to date and procedures should be established to ensure that assessments of dose from any monitoring period reach the individual’s dose record promptly.

5.79. The individual occupational exposure record should be uniquely linked to the worker and should enable the appropriate summation of external and internal doses. For each year, the record should comprise:

- (a) Unique identification of the individual;
- (b) The exposure for the year to date and, where necessary, for the appropriate five-year period;

- (c) Measurements of external dose, and method of assessment:
 - (i) Personal dose equivalent, $H_p(10)$;
 - (ii) If appropriate (e.g. in the case of significant exposure to low energy photon or beta radiation), personal dose equivalent, $H_p(0.07)$;
- (d) Measurements of internal dose:
 - (i) Committed effective dose, $E(50)$;
 - (ii) If appropriate (e.g. in the case of overexposure), committed equivalent dose, $H(50)$;
- (e) Evaluations of anomalous dose results, such as unexpectedly high or low doses;
- (f) The allocated dose for lost or damaged dosimeters or samples;
- (g) Such other information on previous exposure as is needed to demonstrate compliance with the requirements established by the relevant regulatory authority;
- (h) Information about the material and radionuclides involved in any previous known or suspected significant intakes;
- (i) Any special dose limits imposed on the worker;
- (j) Records of formal declarations of pregnancy, any revocations of such declarations, and notifications of the conclusion of a pregnancy;
- (k) Lifetime dose to date.

5.80. Individual dose records should include any assessed equivalent doses or intakes. Details of any involvement in abnormal events should be included, even if estimates of exposure could not be made. It is also important to retain records referencing the objectives, the monitoring methods and the models used for data analysis and interpretation, because these may be needed for future interpretation of the dose records; traceability of the measurements and dose assessment is essential.

5.81. In making records of dose assessments it is important to establish the recording levels of monitoring programmes. A large proportion of the data accumulated in monitoring programmes is of only transitory value; monitoring results are easy to obtain, but the assessment procedure is complex and very often the implied doses are small. The recording level in the context of individual monitoring should be a formally defined level of effective (or equivalent) dose or intake above which a result from a monitoring programme is of sufficient significance to require the measured or calculated value to be included in a dose record. Other results can be covered by a general statement in the record that no unrecorded results exceeded the recording level. However, it is essential that the fact that a measurement has been made be recorded even in these cases. The best way of doing this may be to put a zero in the records. However, if this is done, it should be made clear that this means that the dose was below the recording level. If an

uncertainty of $\pm 100\%$ is considered acceptable at the recording level, this can be used to define the necessary specifications for the low dose performance of personal dosimeters (see the companion Safety Guide [3]).

5.82. The recording level for individual monitoring should be derived from the duration of the monitoring period and an annual effective dose of no less than 1 mSv or an annual equivalent dose of about 10% of the relevant dose limit. However, in situations where several components of the exposure (such as external and internal exposure of specific organs) contribute significantly to the total dose, it may be appropriate to derive lower recording levels for each component. The recording policy for each component should then be formally defined and recorded.

5.83. In practice, for individual monitoring of external exposure, the measured doses are usually entered directly into the records. The minimum level of detection should then be used as the recording level, i.e. results below that level should be recorded as zero. This is satisfactory provided that the minimum level of detection is less than the fraction of the recording level of 1 mSv appropriate (pro rata) for the wear period. For monitoring of internal exposure, a recording level applied to the measured results avoids the unnecessary effort of difficult and time-consuming assessment of trivial intakes.

5.84. Dissemination of information is an important aspect of the record keeping process. The BSS (Ref. [2], para I.47) state that:

“Employers, registrants and licensees shall:

- (a) provide for access by workers to information in their own exposure records;
- (b) provide for access to the exposure records by the supervisor of the health surveillance programme, the Regulatory Authority and the relevant employer;
- (c) facilitate the provision of copies of workers' exposure records to new employers when workers change employment;
- (d) when a worker ceases to work, make arrangements for the retention of the worker's exposure records by the Regulatory Authority, or a State registry, or the registrant or licensee, as appropriate; and
- (e) in complying with (a)–(d), give due care and attention to the maintenance of appropriate confidentiality of records.”

5.85. It follows that recording systems must be capable of producing dose assessment information for any reporting period defined in the RPP or required by regulatory authorities. If a worker changes employment, dose records should be promptly updated and completed.

Records of workplace monitoring

5.86. Management should determine the particular aspects of workplace monitoring that are to be recorded, having regard to the requirements of the BSS: “Records shall be maintained of the results of monitoring and verification of compliance” (Ref. [2], para. 2.40). Management “shall keep appropriate records of the findings of the workplace monitoring programme which shall be made available to workers, where appropriate through their representatives” (Ref. [2], para. I.40). It is important to record data that:

- (a) Demonstrate compliance with regulations;
- (b) Identify significant changes to the working environment;
- (c) Give details of radiation surveys, e.g. date, time, location, radiation levels, instruments used, surveyor, other comments;
- (d) Record reports received about the workplace where compliance with the standards could be adversely affected;
- (e) Detail any appropriate actions taken.

Record retention periods

5.87. Many of these records, for example the full details of a particular radiation survey, are transitory in nature and are only relevant for the lifetime of an established review period, and there may be no need to retain such records for extended periods. Other records may be related to decisions about the definition of the workplace, and these records may be relevant for the lifetime of the workplace. It is likely, for example, that records documenting the creation of designated areas may need to be retained for as long as the designated areas exist. Where the retention period is not specified by the regulatory authority, management should establish an appropriate period for each type of record.

5.88. It is recommended that regulatory authorities should decide which parts of the dose records need to be retained by management for regulatory purposes, and should specify retention periods for each of these. The BSS require that management “shall maintain exposure records for each worker for whom assessment of occupational exposure is required in paras I.32–I.36” (Ref. [2], para. I.44) and that:

“Exposure records for each worker shall be preserved during the worker’s working life and afterwards at least until the worker attains or would have attained the age of 75 years, and for not less than 30 years after the termination of the work involving occupational exposure” (Ref. [2], para. I.49).

5.89. As well as the need to show compliance with dose limits, record retention is important for four additional reasons: to provide data for analysis of dose distributions; to evaluate exposure trends which may take into account collective dose; to optimize the effectiveness of monitoring procedures and programmes; and to provide data for epidemiological studies. Records are also frequently needed for litigation or for workers' compensation cases, which may arise years after the actual or claimed exposure. Written policies for retention and disposal of each type of record should be prepared and maintained. Copies of records should also be accessible to workers, supervisors, employers and the regulatory authority. Workers should be provided with summaries of their individual annual and cumulative exposures if requested by the individual or if required by regulation.

5.90. In general, retention periods should be specified by the regulatory authority. In the absence of such specifications, the following are suggested:

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

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

INFORMATION AND TRAINING

5.92. It is the management's responsibility to ensure that workers who may be occupationally exposed to radiation and persons with assigned responsibilities in the RPP receive general radiation protection information and training.

5.93. Senior management should be trained in the risks associated with ionizing radiation, the basic principles of radiological protection, their main responsibilities regarding radiation risk management and the principal elements of the RPP.

5.94. Workers who may not be occupationally exposed, but whose work may have an impact on the level of exposure of other workers or of members of the public (e.g.

designers, engineers, planners, etc.), should be provided with basic information on radiation protection principles. They should also be trained in how to take account of radiation protection requirements in their activities so as to optimize the protection of other people.

5.95. Training for those workers directly involved in work with radiation sources should include relevant information, presented in the form of documents, lectures and applied training, that emphasizes procedures specific to the worker's job assignment. Particular attention should be paid to contractors, to ensure that they are provided with necessary information and training. Training for workers considered occupationally exposed should address topics at a level of detail commensurate with the workers' job assignments and the potential hazard. The training should cover topics such as the following:

- (a) The main risks associated with ionizing radiation;
- (b) Basic quantities and units used in radiation protection;
- (c) Radiation protection principles (optimization of protection, dose limits, etc.);
- (d) The fundamentals of practical radiation protection, e.g. use of protective equipment, shielding, behaviour in designated areas;
- (e) Specific task related issues;
- (f) Responsibility to advise a designated person immediately if any unforeseen occurrence involving increased radiation risk arises;
- (g) Where appropriate, actions that may need to be taken in the event of an accident.

5.96. Where work involving significant exposure to radiation is to be undertaken, consideration should be given to the use of training on mock-ups or simulators to ensure that the work will proceed as smoothly as possible, that all unnecessary hazards will be avoided and that exposure times will be minimized.

5.97. Individuals whose job assignments are incidental to the use of radiation, such as caretakers/janitors or security staff, and others who may spend brief periods in areas where exposure is possible, should be given basic information on the hazards and any preventive actions to be taken. For such individuals, there is need only to include a brief discussion of items such as the use of time and distance to limit exposure, a qualitative discussion of the trivial risk from the minimal exposure they may receive and specific directives regarding prohibited, required or recommended actions.

5.98. The specific requirements of the BSS relating to female workers who may enter controlled or supervised areas are reproduced in para. 5.33. In addition, management should consider the possible need for further information and training related to any

change of working conditions to restrict exposure of the foetus following a declaration of pregnancy.

5.99. Workers' knowledge of the fundamentals of radiation protection and safety, their level of training and their competence to perform the specified tasks safely should be evaluated, and determined to be adequate, prior to any unsupervised assignment. A process for the evaluation of workers' knowledge, level of training and competence should be established.

5.100. Radiological protection information and training programmes should be documented and approved at an appropriate level within the organization. Such programmes should be reviewed periodically to ensure that they remain up to date. Formal records of each worker's training and testing should be maintained, and retained for three years after cessation of employment. Periodic retraining should be provided to ensure that workers have the most up to date knowledge relevant to their work, and that they do not become complacent about workplace hazards. Retraining should also be undertaken when there are significant changes in policy or procedures. Training should be updated at regular intervals.

QUALITY ASSURANCE

5.101. The BSS (Ref. [2], paras IV.24–IV.25) require that a quality assurance (QA) programme be established as part of the RPP:

“Registrants and licensees shall be responsible for establishing the quality assurance programme required by the principal requirements of these Standards, and the nature and extent of the quality assurance programme shall be commensurate with the magnitude and the likelihood of the potential exposures from the sources for which they are responsible.”

“The quality assurance programme shall provide for:

- (a) planned and systematic actions aimed at providing adequate confidence that the specified design and operational requirements related to protection and safety are satisfied, including provisions for feedback of operational experience;
- (b) a framework for the analysis of tasks, development of methods, establishment of norms and identification of necessary skills for the design and operation of the source; and
- (c) validation of designs and supply and use of materials, of manufacturing, inspection and testing methods, and of operating and other procedures.”

5.102. Extensive guidance on the development of quality systems appears in the reports of the ISO 9000 series [18], appropriate guides by the ISO and the International Electrotechnical Commission (IEC), and a number of other reports; the IAEA has published such a report for nuclear power plants and other nuclear installations [19]. This guidance can be applied to both products and services. The specific details of the requirements, structure and implementation of QA programmes depend on the national regulatory structure and local conditions, including the resources available, and often on personnel.

5.103. Maintaining the effectiveness of any RPP relies on the ability of those in charge of implementing its various components to adopt a QA programme and to pay as much attention as possible to lessons learned from experience. The evaluation, through appropriate reviews and audits, of the way in which the RPP is implemented and of the quality of the RPP itself are key elements of an effective programme.

5.104. Management should be committed to QA and should provide the financial and human resources necessary to achieve quality standards and to maintain them continuously.

5.105. The principal objective of incorporating QA principles into the RPP is to improve safety by establishing confidence in the results of the RPP. Additional benefits are the strengthening of efficiency and effectiveness by establishing a system for improving the RPP based on the use of relevant experience (lessons learned), the identification and prompt correction of deficiencies, and the monitoring of performance.

5.106. In particular, QA programmes should be established for dosimetry services (see para. 5.62). The nature and extent of the QA programme should be consistent with the number of workers monitored, and the expected magnitude and likelihood of exposures in the workplaces covered by the monitoring programme [3, 4]. Of particular importance is the ISO/IEC Guide 25 [20], which is used by many regulatory authorities to accredit testing and calibration programmes. The quality of a dosimetry service depends strongly upon the involvement and commitment of the service's staff.

5.107. The QA programme may be divided functionally into management, performance and assessment activities. Within any organization developing an RPP, management ownership, authority and responsibilities should be clearly established and documented. Management should have overall authority and responsibility for the RPP, including those aspects associated with the assurance of quality.

5.108. Management should be responsible for:

- (a) Establishing, implementing and maintaining the QA programme;
- (b) Ensuring that the RPP personnel are competent to perform the work;
- (c) Ensuring that items, services and processes which do not meet criteria are identified and promptly corrected;
- (d) Ensuring that documents establishing the RPP are prepared, reviewed, approved, issued, distributed, authorized and revised as appropriate;
- (e) Establishing a record management system that provides for the identification, filing, safe storage, maintenance, retrieval and disposal of records;
- (f) Establishing a procurement system which ensures that purchased items meet established criteria and perform as expected;
- (g) Establishing which work needs testing for acceptance.

5.109. Operational staff should be responsible for:

- (a) Planning and performing work in accordance with appropriate standards, approved procedures, work instructions and any other established requirements;
- (b) Using sound scientific and engineering principles and verified inputs in the design process;
- (c) Procuring items, equipment and materials from qualified vendors under controlled conditions;
- (d) Ensuring that items, equipment and services are inspected or tested to demonstrate that they will perform as intended. The calibration of measuring devices is an example of such testing.

AUDITS AND REVIEWS

5.110. The RPP should be assessed on a regular basis. Audits and/or reviews of activities within the RPP should be scheduled on the basis of the status and importance of the activity. Management should establish a process for such assessments to identify and correct administrative and management problems that may prevent the achievement of programme objectives. Audits and reviews should be conducted by persons who are technically competent to evaluate the processes and procedures being assessed, but do not have any direct responsibility for those activities. These may be staff from other work areas within the organization, or there may be advantages in independent assessment by other organizations. The objective of such assessments is to enhance the effectiveness and efficiency of the RPP.

5.111. Audits and reviews should be performed in accordance with written procedures and checklists. They should be conducted when one or more of the following conditions prevail:

- (a) When required by the regulatory authority;
- (b) When a systematic independent assessment of the programme is considered necessary by management;
- (c) Following the implementation of a new RPP or substantive programme element;
- (d) When significant changes are made to functional areas of the RPP, such as significant reorganization or procedural revision;
- (e) When necessary to verify implementation of previously identified corrective actions.

6. INTERVENTION IN EMERGENCIES

GENERAL

6.1. Emergency exposure situations requiring protective actions to reduce or avert exposures are considered in Section 3 of the BSS (Ref. [2]). The basic obligations are to undertake protective actions whenever they are justified, and to optimize those actions so as to produce the maximum net benefit. Paragraph 3.5 of the BSS states: “In the case of emergency exposure situations, protective actions are not normally likely to be necessary unless intervention levels or action levels are or may be exceeded.” Further information on safety of sources and emergency exposure situations is given Appendices IV and V of the BSS.

EMERGENCY PLANNING AND RESPONSIBILITIES

6.2. Emergency exposure situations may arise as a consequence of an accident. In most accidents, the on-site consequences are likely to predominate. The protection of workers involved in implementing protective actions in emergency exposure situations is discussed below.

6.3. The BSS (Ref. [2], para. 3.9) require that:

“Each registrant or licensee responsible for sources for which prompt intervention may be required shall ensure that an emergency plan exists that defines on-site responsibilities and takes account of off-site responsibilities appropriate for the source and provides for implementation of each form of protective action...”

The decision whether or not emergency plans are needed should result from the prior radiological evaluation referred to in Section 5. Furthermore, this prior radiological evaluation should indicate the essential features that need to be incorporated within the plan, the degree of planning being commensurate with the nature and magnitude of the risk and the feasibility of mitigating the consequences should an accident or emergency occur.

6.4. The BSS state that emergency plans should “specify how the responsibilities for the management of interventions will be discharged on the site, off the site and across national boundaries” (Ref. [2], para. V.2). Paragraph 3.7 of the BSS specifically states that “for occupational exposures incurred by workers undertaking intervention, the responsibilities...shall be discharged by the registrant or licensee, the employer and the Intervening Organizations, as required by the Regulatory Authority.” It is further stated in para. V.29 that “The legal person responsible for ensuring compliance with the foregoing requirements shall be specified in emergency plans.”

6.5. If only minor accidents have to be considered, the registrant or licensee should draw up a contingency plan, based on an assessment of the consequences of any reasonably foreseeable accident or incident, in order to restrict as far as is reasonably achievable any resulting exposure of workers on-site. Under many circumstances such contingency plans may be very simple.

THE IMMEDIATE AFTERMATH OF AN ACCIDENT

6.6. Emergency and contingency plans should include a system for categorizing workers involved in the immediate aftermath of the accident — for example a list of persons involved and their locations — and a system to give a rapid initial assessment of dose (see Ref. [2], paras V.24–V.25). Provision should also be made for appropriate decontamination facilities and for the reception and treatment in a local hospital of workers suspected of being contaminated or having contaminated wounds, or of having been exposed to doses near or in excess of the thresholds for deterministic effects. If a local hospital is not available, special emergency transport to hospital should be provided, by air if necessary.

EMERGENCY ACTIONS

6.7. In the case of large sources, and nuclear power facilities in particular, workers may need to be involved in actions to protect the public. In such cases, the avoidance of dose to the public (dose averted) should be balanced against the detriment associated with the intervention, including the dose to these workers.

6.8. Appendix V of the BSS (Ref. [2]) gives detailed guidance on emergency exposure situations. Intervention criteria for use in nuclear or radiation emergencies have been elaborated in IAEA Safety Series No. 109 [21].

6.9. Emergency plans prepared in advance should include definition of the roles and responsibilities of all workers concerned in the emergency response. Details of protective actions to be taken, protective clothing and monitoring instruments to be used, and dosimetry arrangements should also be specified. Consideration should be given to isolating the affected parts of the installation and ensuring that only authorized persons enter this area, in a controlled manner.

PROTECTION OF WORKERS UNDERTAKING INTERVENTION

6.10. The fundamental difference between members of the public and workers in situations requiring intervention is that members of the public will receive doses unless some action is taken to prevent them, whereas workers will not receive doses (except during the initial course of an accident) unless a decision is made to expose them to the source. Thus, in most cases, it is reasonable to continue to treat workers' exposures within the system of protection for practices, particularly so in the latter stages of intervention. Because the exposure is deliberate and controlled, the dose limits for workers should be assumed to apply unless there are overriding reasons not to apply them, such as the need to save life immediately after an accident or to prevent the development of catastrophic conditions.

6.11. It therefore follows that the doses to workers undertaking intervention should, if at all feasible, be kept below the maximum single year dose limit for occupational exposure, which in the case of effective dose is 50 mSv. Paragraph V.28 of the BSS (Ref. [2]) specifically requires workers undertaking tasks which might cause them to receive a dose above the maximum single year dose limit to be volunteers. However, it is stated in a footnote that if military personnel are involved, this requirement may not apply in some circumstances. The footnote also implies that the levels of dose discussed above for workers involved in undertaking actions may not necessarily apply to military personnel. Nevertheless, it states that the exposure of such personnel should be limited to levels specified by the regulatory authority.

6.12. The BSS (Ref. [2], para. V.27) envisage three situations where it would be justified for the dose limits to be exceeded, as follows:

- “(a) for the purpose of saving life or preventing serious injury;
- (b) if undertaking actions intended to avert a large collective dose; or
- (c) if undertaking actions to prevent the development of catastrophic conditions.”

6.13. For these situations the objective, in general, should be to keep doses below twice the maximum single year dose limit (i.e. below an effective dose of 100 mSv or equivalent doses of 1 Sv to the skin and 300 mSv to the lens of the eye). However, where life saving actions are concerned, significantly higher levels of dose could be justified, although every effort should be made to keep doses below ten times the maximum single year dose limit in order to avoid deterministic effects on health (i.e. below an absorbed dose to the whole body of 500 mGy or an absorbed dose to the skin of 5 Gy). Workers undertaking actions in which their doses may approach or exceed ten times the maximum single year dose limit shall do so only when the benefits to others clearly outweigh their own risk.

6.14. In a footnote to para. V.27 of the BSS it is noted that “Workers undertaking an intervention may include, in addition to those employed by registrants and licensees, such assisting personnel as police, firemen, medical personnel and drivers and crews of evacuation vehicles”. Such workers should be treated as discussed in paras 6.16–6.20 below.

6.15. Paragraph V.28 of the BSS (Ref. [2]) specifically requires workers who may receive a dose greater than the maximum single year dose limit to “be clearly and comprehensively informed in advance of the associated health risk, and shall to the extent feasible, be trained in the actions that may be required.” These actions relate to the protection of the public and themselves. In particular, information and, where necessary, training should be provided on protective measures, such as respiratory protection, use of protective clothing, means of shielding and iodine prophylaxis. Where workers may be exposed to radiation fields with relatively high dose rates, pre-established guidance should be given on dose, dose rates and air concentrations for the appropriate time period.

Categories of workers

6.16. The BSS require that “All reasonable steps shall be taken to... assess and record the doses received by workers involved in emergency intervention” (Ref. [2], para. V.31). It is convenient to consider the arrangements for the monitoring and assessment of doses for three broad categories of workers:

- (a) Category 1: Workers in this category — those undertaking urgent action at the site of the accident — act to save life, or to prevent serious injury or a substantial increase in the potential doses to members of the public. They are most likely to be plant personnel, but may also be emergency service workers such as fire fighters.
- (b) Category 2: Workers in this category, such as police, medical personnel, drivers and crew of vehicles used for evacuation, act to protect the public in the early accident phase and will incur additional exposure in order to avert doses to the public. They are not normally regarded as being occupationally exposed to radiation, but in the event of an emergency action they should be included in the whole system of protection measures.
- (c) Category 3: Workers in this category undertake recovery operations after the end of the emergency phase of the intervention. These operations include repairs to the plant and site, disposal of waste and decontamination of the site and the environment.

Management of workers in the emergency phase

6.17. Doses incurred by workers during the emergency phase of the intervention should be recorded separately, if possible, from the doses incurred during routine work, but should be noted on the workers' dose records. The degree of accuracy required for any dose assessment should increase with the level of exposure likely to have been received by the worker. Some pre-established guidance may help in the management of the workers in Category 1, expressed in terms both of dose and of directly measurable quantities such as dose rates or air concentration. The doses to workers in Categories 1 and 2 should be monitored on an individual basis, using means appropriate to the situation, such as direct reading or alarm dosimeters. The BSS also state that "When the intervention has ended, the doses received and the consequent health risk shall be communicated to the workers involved" (Ref. [2], para. V.31).

6.18. Paragraph V.32 of the BSS (Ref. [2]) states that:

"Workers shall not normally be precluded from incurring further occupational exposure because of doses received in an emergency exposure situation. However, qualified medical advice shall be obtained before any such further exposure if a worker who has undergone an emergency exposure receives a dose exceeding ten times the maximum single year dose limit or at the worker's request."

A particular concern should be whether the worker has received a dose sufficient to cause serious deterministic effects.

6.19. These arrangements regarding the control of doses to workers undertaking intervention should only be permitted during the emergency phase. Paragraph V.30 of the BSS (Ref. [2]) states that:

"Once the emergency phase of an intervention has ended, workers undertaking recovery operations, such as repairs to plant and buildings, waste disposal or decontamination of the site and surrounding area, shall be subject to the full system of detailed requirements for occupational exposure..."

6.20. The dose assessment of workers in Category 3 should be the same as for any occupationally exposed worker, subject to the normal system of radiation protection, although it is noted that there may be a need to make use of the dose limits for special circumstances discussed in Section 3.

7. HEALTH SURVEILLANCE

OBJECTIVES OF HEALTH SURVEILLANCE

7.1. Paragraph I.43 of the BSS (Ref. [2]) states that:

"Health surveillance programmes shall be:

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

7.2. Further objectives of health surveillance are to provide a baseline of information that can be used in the case of accidental exposure to a particular hazardous agent or occupational disease and for specific counselling of workers with respect to any radiological risks to which they are or might be subjected, and to support the management of overexposed workers.

RESPONSIBILITIES IN RELATION TO HEALTH SURVEILLANCE

7.3. Paragraph I.41 of the BSS (Ref. [2]) requires that "Employers, registrants and licensees shall make arrangements for appropriate health surveillance in accordance

with the rules established by the Regulatory Authority.” In-house services or external consultants may be used.

7.4. The BSS (Ref. [2], para. I.42) state that:

“If one or more workers are to be engaged in work that involves or could involve exposure from a source that is not under the control of their employer, the registrant or licensee responsible for the source shall as a precondition for such engagement make any special arrangements for health surveillance with the employer which are needed to comply with the rules established by the Regulatory Authority.”

MEDICAL EXAMINATION OF WORKERS

7.5. Medical examinations of occupationally exposed workers should follow the general principles of occupational medicine. There should be examinations before radiation work commences and periodic reviews thereafter.

7.6. The initial examination should assess the health of workers and their fitness for the intended tasks, and also identify those workers who have a condition that might necessitate particular precautions during work. It should, however, be rare for the radiation component of the working environment to significantly influence the decision about the fitness of a worker to undertake work with radiation, or to influence the general conditions of service.

7.7. Three situations may need to be considered in the initial medical examination and in the subsequent reviews:

- (a) The fitness of a worker for wearing respiratory protection devices (if the work involves the use of such devices);
- (b) The fitness of a worker with a skin disease, such as eczema or psoriasis (if the work involves handling unsealed sources);
- (c) The fitness of a worker known to have a psychological disorder for work with radiation sources.

7.8. The periodic reviews should focus on confirming that no clinical condition which could prejudice the health of the worker has developed while working with radiation. The nature of the review should depend on the type of the work that is undertaken, on age and health status, and possibly on the habits of the worker (e.g. smoking habits). Examinations should normally be as frequent as in any other occupational health surveillance programme. Frequency should depend on the

state of health and the type of work, but would typically be every year or every two years. Where the character of the work creates a potential for localized skin damage from irradiation, particularly to the hands, the skin should be examined periodically.

7.9. Health surveillance records should be confidential, and preserved in a manner approved by the regulatory authority. The minimum period of record keeping should be the lifetime of the worker concerned. However, because of the possibility of litigation, longer retention of records may be advisable (see para. 5.90).

7.10. In determining fitness to wear respiratory protection devices, examinations should involve checks of the integrity of lung function. In the case of workers with skin diseases, the decision regarding fitness should be based on the nature, extent and evolution of the disease and the nature of the job. Workers with such diseases may not need to be excluded from work with unsealed radioactive materials if the levels of activity are low and appropriate precautions, such as covering the affected parts of the body, are taken. In the case of workers with psychological disorders, the decision on fitness should take account of the safety implications of symptomatic episodes of the disease. The primary concern is whether such workers could represent a danger to themselves or to their co-workers.

7.11. There is no inherent reason why workers who have previously undergone radiotherapy should be excluded from work with radiation. Each case should be evaluated individually, taking into account the quality of the cure, general prognosis and other health considerations, the understanding and wishes of the worker, and the nature of the work.

INFORMATION AND TRAINING FOR THE PHYSICIAN

7.12. The physician in charge of the health surveillance of workers should have access to all information concerning the working conditions that may influence the workers' health, and to the formal dose records for each individual worker. The physician should also be familiar with the nature of, and working conditions for, particular jobs and work, which are of the utmost importance in deciding the fitness of a person for such work. Some of this information may need to be transferred to the individual's medical record, which should be confidential. However — with due attention to the protection of privacy, and on condition that information on occupational exposure will not be used for discriminatory purposes or in any other manner prejudicial to workers' interests — interested parties should have access to the information relevant to radiation protection and safety, especially that concerning

the circumstances and levels of any overexposure, remedial actions undertaken and lessons learned, including how to avoid a recurrence.

7.13. To be able to deal with workers' safety, concerns and treatment related to radiation, the occupational physician should be adequately trained in radiological protection, and this knowledge should be periodically updated. This training should provide an understanding of the biological effects of radiation (both stochastic and deterministic) and the risks associated with exposure, both from routine operations and as a consequence of accidents [22]. These risks should be placed in the context of other occupational risks. Additionally, the physician should be familiar with the precautions and procedures that are used to protect workers.

COUNSELLING

7.14. Specific counselling by the occupational physician, sometimes supported by specialists, should be available to the following categories of workers:

- (a) Women who are or may become pregnant, or are breast feeding a child;
- (b) Individual workers who have been or may have been exposed substantially in excess of the dose limits;
- (c) Workers who may be worried about their radiation exposure;
- (d) Workers who otherwise request such counselling.

7.15. The occupational physician should have sufficient knowledge of the biological effects of radiation exposure to be able to inform the worker of the radiological risks associated with all of the above situations. The occupational physician should also be able to advise management on the need for any particular precautions or procedures regarding the working conditions of pregnant women, and to advise pregnant workers of any particular precautions that they themselves should take. In the case of accidental exposure or overexposure, the occupational physician should co-operate with management to ensure that all suitable arrangements for evaluating the severity of the exposure are implemented.

MANAGEMENT OF OVEREXPOSED WORKERS

7.16. In accordance with the conditions of authorization, management should draw up formal plans to deal with situations in which workers might be overexposed. These

plans should address the management of overexposed workers and the health consequences that might be encountered. They should specify the necessary actions to be taken, and management should allocate resources for carrying out those actions. Additional guidance related to medical response to accidents and radiological emergencies can be found in two IAEA Safety Reports [23, 24].

7.17. If a substantial overexposure is suspected to have occurred, management should promptly undertake an investigation to assess the dose received by the worker(s) concerned. The investigation should include the reading of personal dosimeters and any monitoring instruments and, in the case of internal exposure, in vivo or in vitro monitoring as appropriate.

7.18. Assessed doses that are close to dose limits are unlikely to call for anything more than an investigation of the causes, so that the appropriate lessons can be drawn. They do not necessitate any special medical investigations or treatment. Only at doses much higher than the dose limits (i.e. 0.2–0.5 Sv or higher) will special dose investigations involving biological dosimetry (e.g. chromosomal aberration analysis in somatic cells, mainly lymphocytes) and further extended diagnosis or medical treatment be necessary. The medical treatment of those persons exposed to high levels of external radiation should address any adverse health effects, particularly deterministic effects.

7.19. Measures to reduce doses may be warranted in the event of a worker's having suffered a significant intake of radioactive material. Such workers should be forewarned of the possibility of medical intervention to reduce the dose uptake in certain situations. The action to be taken will depend on the radionuclide(s) involved, the magnitude of the committed equivalent dose to relevant organs and the efficiency of and risk associated with the protective measure. The action should only be implemented when the dose reduction would outweigh the side effects. Examples of such therapies include increasing the rate of removal of actinides from the body by DTPA (diethylenetriamine pentaacetic acid) treatment, forced diuresis after an intake of tritium, and surgical excision of contaminated wounds.

7.20. Detailed investigations of accidents, their circumstances and consequences should involve specialists in different fields, particularly the physician and health physicist. There should be close liaison between these specialists in order to ensure that all actions undertaken to provide medical treatment are correctly co-ordinated. When it is suspected that the doses received are close to or above the thresholds for deterministic effects, the investigation should determine as accurately as possible the absorbed doses and their distribution over the body, and should include appropriate medical examinations of the affected worker(s).

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