IAEA Safety Standards
for protecting people and the environment

Radiation Safety of Gamma, Electron and X Ray Irradiation Facilities

Specific Safety Guide
No. SSG-8

IAEA
International Atomic Energy Agency

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

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The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at PO Box 100, 1400 Vienna, Austria.

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RADIATION SAFETY OF GAMMA, ELECTRON AND X RAY IRRADIATION FACILITIES

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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".

IAEA SAFETY STANDARDS SERIES No. SSG-8

RADIATION SAFETY OF GAMMA, ELECTRON AND X RAY IRRADIATION FACILITIES

SPECIFIC SAFETY GUIDE

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Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 2600 29302
tel.: +43 1 2600 22417
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FOREWORD

The IAEA's Statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property — standards which the IAEA must use in its own operations, and which a State can apply by means of its regulatory provisions for nuclear and radiation safety. A comprehensive body of safety standards under regular review, together with the IAEA's assistance in their application, has become a key element in a global safety regime.

In the mid-1990s, a major overhaul of the IAEA's safety standards programme was initiated, with a revised oversight committee structure and a systematic approach to updating the entire corpus of standards. The new standards that have resulted are of a high calibre and reflect best practices in Member States. With the assistance of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its safety standards.

Safety standards are only effective, however, if they are properly applied in practice. The IAEA's safety services — which range in scope from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations — assist Member States in applying the standards and appraise their effectiveness. These safety services enable valuable insights to be shared and all Member States are urged to make use of them.

Regulating nuclear and radiation safety is a national responsibility, and many Member States have decided to adopt the IAEA's safety standards for use in their national regulations. For the contracting parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by designers, manufacturers and operators around the world to enhance nuclear and radiation safety in power generation, medicine, industry, agriculture, research and education.

The IAEA takes seriously the enduring challenge for users and regulators everywhere: that of ensuring a high level of safety in the use of nuclear materials and radiation sources around the world. Their continuing utilization for the benefit of humankind must be managed in a safe manner, and the IAEA safety standards are designed to facilitate the achievement of that goal.

THE IAEA SAFETY STANDARDS

BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures[1] have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. The safety requirements use ‘shall’ statements together with statements of

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[1] See also publications issued in the IAEA Nuclear Security Series.

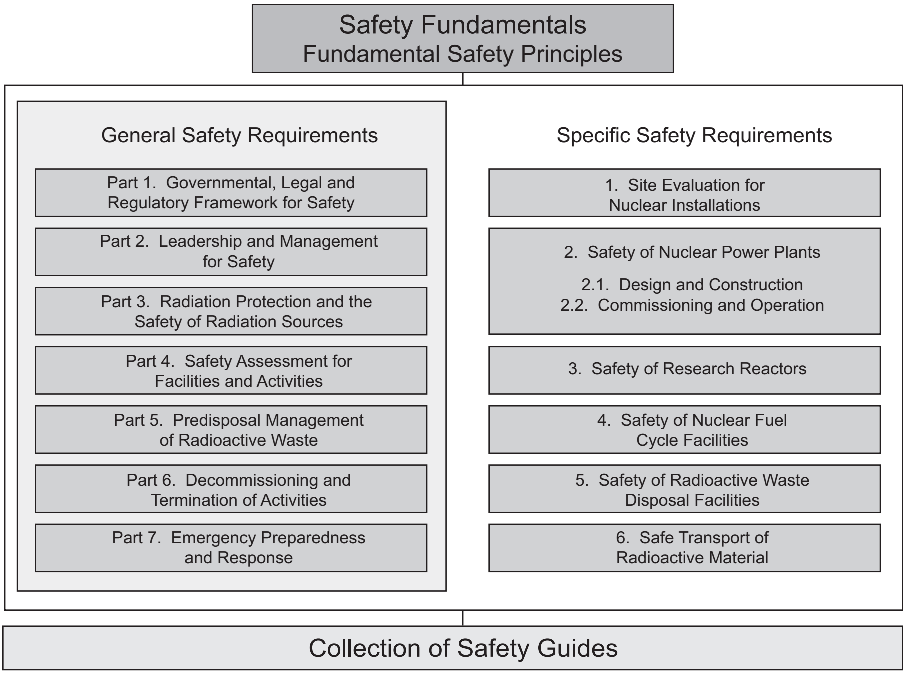

FIG. 1. The long term structure of the IAEA Safety Standards Series.

associated conditions to be met. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and four safety standards committees, for nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

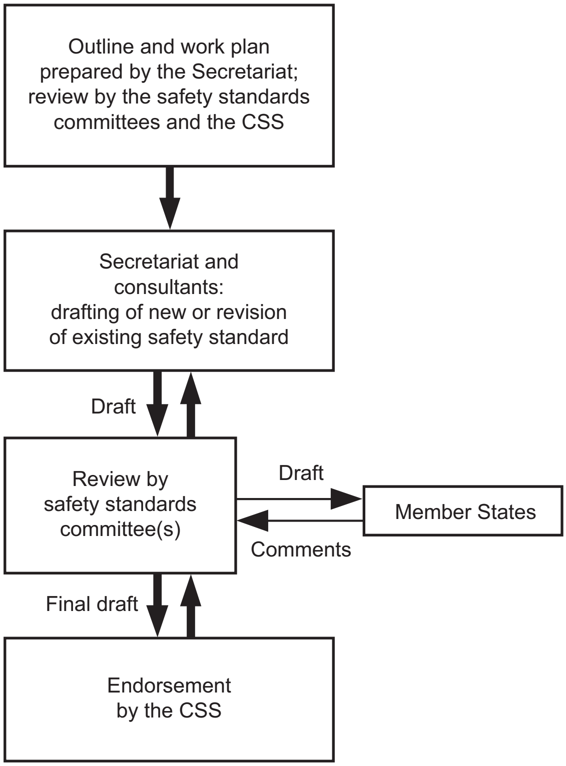

FIG. 2. The process for developing a new safety standard or revising an existing standard.

All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards. It articulates the mandate of the IAEA, the vision for the future application of the safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see http://www-ns.iaea.org/standards/safety-glossary.htm). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. The applications of ionizing radiation bring many benefits to humankind, ranging from power generation to uses in medicine, industry and agriculture. Irradiators that utilize ionizing radiation are used in a variety of beneficial applications such as food irradiation and sterilization of medical products. However, ionizing radiation can also be harmful unless it is properly controlled. Industrial irradiators produce very high dose rates during irradiation, such that a person accidentally present in the radiation room[1] could receive a lethal dose within minutes or even seconds.

1.2. Several fatalities have occurred in gamma irradiators in various States. In addition, serious overexposures have occurred at electron beam irradiators in several States. The IAEA has investigated these and other accidents, and has published a report [1] on lessons learned so that similar accidents may be prevented in the future.

1.3. The accidents described in Ref. [1] involved workers who entered radiation rooms unaware of the high dose rates. There are also other potential radiation hazards at gamma irradiators, including contamination from damaged radioactive sources, sources becoming dislodged from source racks, accidents in handling sources, fires and breaches in security.

1.4. The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS) [2] establish the basic requirements for protection of people against exposure to ionizing radiation and for the safety of radiation sources[2]. The implementation of these requirements at irradiation facilities is intended to prevent accidents of the type described here and, generally, to provide for the best possible protection and safety measures under the prevailing circumstances. The magnitudes and likelihood of exposures and the numbers of individuals exposed are required to be kept as low as reasonably achievable, economic and social factors being taken into account.

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[1] The radiation room is that region of the irradiator that is enclosed by radiation shielding and is made inaccessible when the radiation source is in use.

[2] The term ‘radiation source’ includes radioactive sources and radiation generators. ‘Radiation’ as used in the IAEA safety standards means ionizing radiation.

1.5. Unless otherwise stated, terms are used with the meanings ascribed to them in the IAEA Safety Glossary (2007 Edition) [3].

OBJECTIVE

1.6. The objective of this Safety Guide is to provide recommendations on how to meet the requirements of the BSS with regard to irradiation facilities. This Safety Guide provides specific, practical recommendations on the safe design and operation of gamma, electron and X ray irradiators for use by operating organizations and the designers of these facilities, and by regulatory bodies.

SCOPE

1.7. The facilities considered in this publication include five types of irradiator, whether operated on a commercial basis or for research and development purposes. This publication is concerned with radiation safety issues and not with the uses of irradiators, nor does it cover the irradiation of product[3] or its quality management. The five types of irradiator are:

- — Panoramic dry source storage irradiators (see Fig. 1);
- — Underwater irradiators, in which both the source and the product being irradiated are under water (see Fig. 2);
- — Panoramic wet source storage irradiators (see Fig. 3);
- — Electron beam irradiation facilities, in which irradiation is performed in an area that is potentially accessible to personnel, but that is kept inaccessible during the irradiation process (see Fig. 4);
- — X ray irradiation facilities, in which irradiation is performed in an area that is potentially accessible to personnel, but that is kept inaccessible during the irradiation process (see Fig. 5).

Consideration of non-radiation-related risks and of the benefits resulting from the operation of irradiators is outside the scope of this Safety Guide. The practices of radiotherapy and radiography are also outside the scope of this Safety Guide. Category I gamma irradiators (i.e. ‘self-shielded’ irradiators) are outside the scope of this Safety Guide.

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[3] Product in this context means the objects or materials that are intentionally irradiated.

STRUCTURE

1.8. Designs of irradiation facilities are categorized according to radiation type and methods of accessibility and shielding, as described in Section 3 of this Safety Guide. The notification and authorization of irradiation practices, the responsibilities of the operating organization and general radiation safety issues are discussed in Section 4. The individual monitoring of workers and workplace monitoring are described in Sections 5 and 6, respectively.

1.9. Section 7 provides a description of security measures for controlling radioactive sources. Section 8 deals with design and operational safety aspects of irradiation facilities. Section 9 discusses the testing and maintenance of equipment.

1.10. Section 10 focuses on the transport and loading and unloading of radioactive sources. Section 11 addresses emergency preparedness and emergency response.

2. JUSTIFICATION OF PRACTICES

2.1. The Fundamental Safety Principles [4] state the fundamental safety objective as being to protect people and the environment from harmful effects of ionizing radiation. Principle 4, Justification of facilities and activities, states that "Facilities and activities that give rise to radiation risks must yield an overall benefit." This may be taken as being equivalent to the well established principle of justification of practices, the operation of irradiation facilities being one example [2].

2.2. The basic requirements for radiation protection for practices established in the BSS [2] are: justification of practices, individual dose limits, and optimization of protection and safety. The basic requirement for the justification of practices is expressed as follows:

> "No practice or source within a practice should be authorized unless the practice produces sufficient benefit to the exposed individual 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" (Ref. [2], para. 2.20).

2.3. When the principle was first formally expressed, many practices such as the operation of irradiators were already in widespread use, and in general their justification was implicit. Under normal conditions, the design, construction, operation and maintenance of irradiators result in negligible doses to workers and the public. However, as indicated above, the operation of irradiators occasionally results in doses to workers in excess of authorized limits as a result of accidents. Also, the operation of irradiators carries with it other radiation risks, including those associated with the security of radioactive sources, the transport of radioactive sources and, ultimately, the disposal of radioactive sources.

2.4. The decision as to whether the operation of irradiators is justified is specific to the circumstances and benefits of their use, taking into account national priorities; thus definitive recommendations regarding justification cannot be provided. Ultimately, the decision as to whether the operation of an irradiator is justified should be made on a case by case basis by the appropriate governmental authority, which should weigh the various benefits and risks associated with its use in determining whether the specific practice is justified. The governmental authority's decision as to whether the operation of irradiators in the State is justified may also be made on a general basis for all irradiators of a specific type.

3. TYPES OF IRRADIATOR

GAMMA IRRADIATION FACILITIES

3.1. For the purposes of this Safety Guide, there are four general categories of gamma irradiator, defined on the basis of the design of the facility and, in particular, the accessibility and shielding of the radioactive source[4,5]. Category I gamma irradiators (i.e. self-shielded irradiators) are not dealt with in this Safety Guide, since they are distinct for the purposes of radiation safety. For the purposes of this Safety Guide, the relevant categories of gamma irradiator are

[4] The four categories of gamma irradiator have historically been designated with Roman numerals I–IV. The categories of gamma irradiator should not be confused with the categories used in the IAEA's Categorization of Radioactive Sources [5], which uses Arabic numerals 1–5.

[5] In this context the term 'radioactive source' may apply to one individual sealed source or collectively to a number of radioactive sources in a source array.

Category II (panoramic dry source storage irradiators), Category III (underwater irradiators) and Category IV (panoramic wet source storage irradiators).

Category II (panoramic dry source storage irradiators)

3.2. A panoramic dry source storage irradiator is a controlled human access irradiator in which the radioactive source is: enclosed in a dry container constructed of solid materials, fully shielded[6] when not in use and exposed within an area that is kept inaccessible during operation by means of an entry control system (Fig. 1).

3.3. Dry source storage facilities generally consist of either a built-in or a transportable radioactive source storage container constructed of solid materials. Inserts, brackets and other hardware are used to anchor or hold in place such items as the source holder[7], guide rods or cables, and various pipes for other services.

3.4. Components of irradiators that are subjected to high dose rates should be resistant to radiation damage. Surfaces in close proximity to radioactive sources should be able to be easily decontaminated and should be constructed of materials that are corrosion resistant and metallurgically compatible with each other and with other components, including the source capsules[8]. The irradiator should be designed to maintain the integrity of its radiation shielding under conditions of normal use, anticipated operational occurrences and plausible accident conditions such as fire conditions.

Category III (underwater irradiators)

3.5. A self-contained wet source storage irradiator is an irradiator in which the radioactive source is stored in a pool of water, the source is shielded at all times, and human access to the source and to the volume undergoing irradiation is physically restricted in its designed configuration and proper mode of use (Fig. 2).

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[6] ‘Fully shielded’ means the condition in which the source is stored is such that dose rates in the radiation room are optimized, allowing the room to be occupied by workers.

[7] The source holder is that component of the irradiator within which the radioactive source is positioned, including any retaining screws, pins, clips, etc.

[8] The source capsule is the protective envelope of a sealed source which prevents leakage of radioactive material.

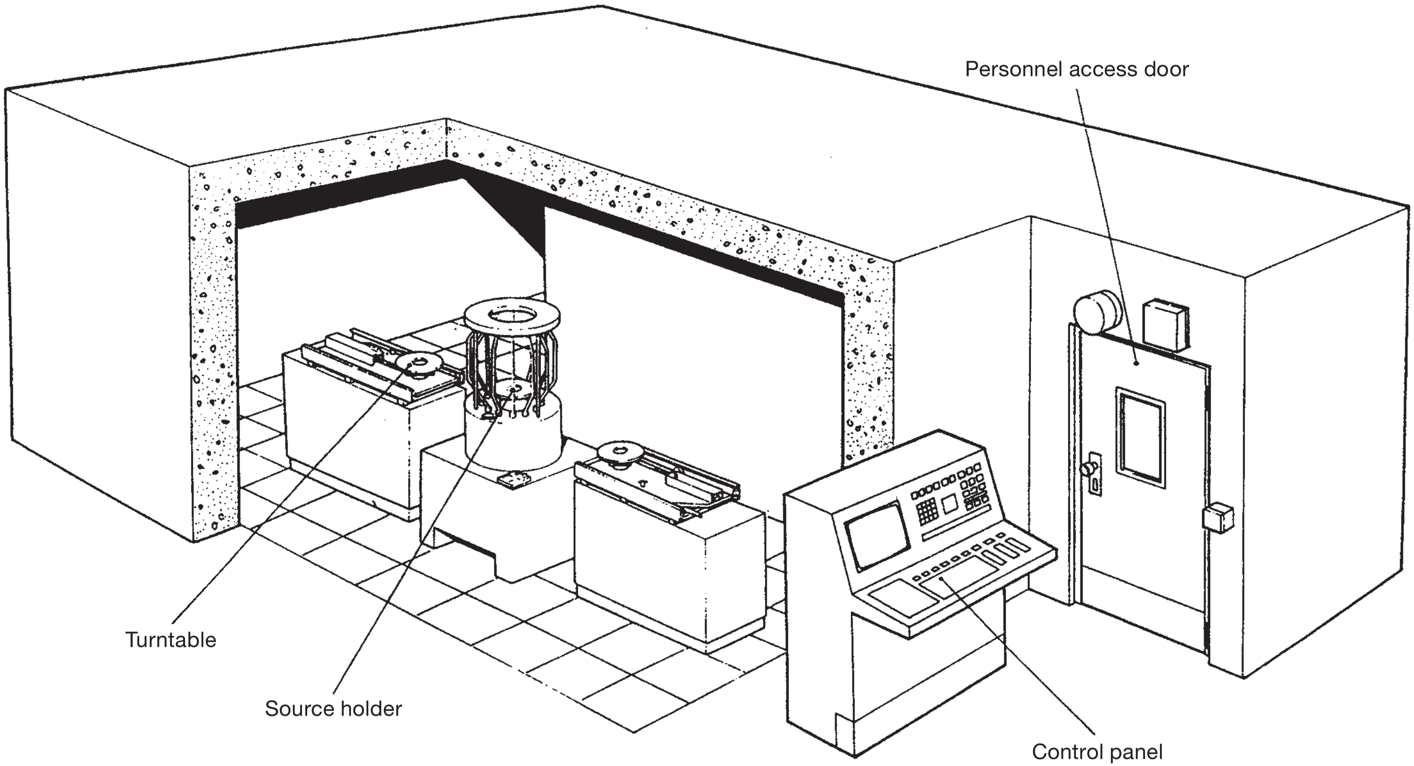

FIG. 1. Category II gamma irradiation facility: Panoramic dry source storage irradiator.

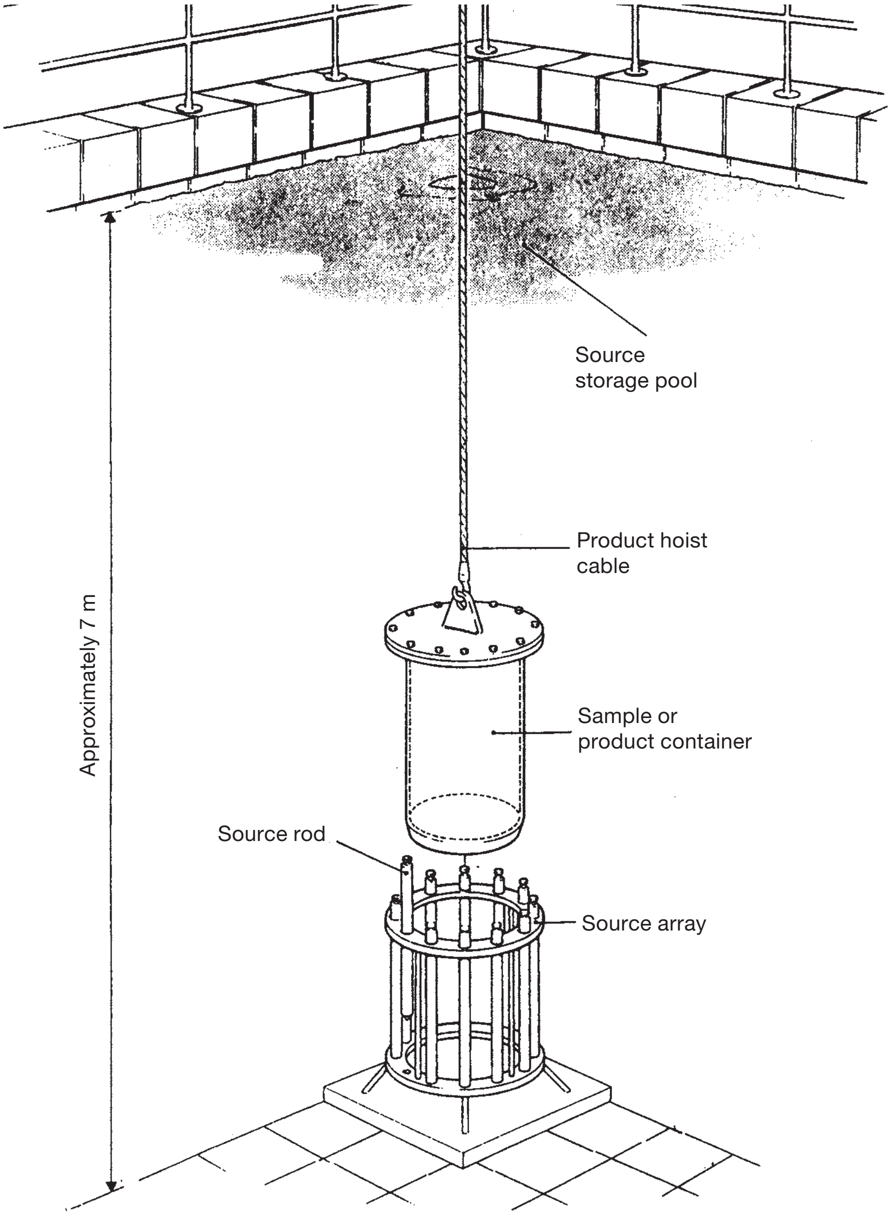

FIG. 2. Category III gamma irradiation facility: Underwater irradiator.

Category IV (panoramic wet source storage irradiators)

3.6. A panoramic wet source storage irradiator is a controlled human access irradiator in which the radioactive source is stored and fully shielded in a pool of water when not in use. The source is exposed within a radiation room that is kept inaccessible during operation by means of an entry control system (Fig. 3).

IRRADIATION FACILITIES WITH RADIATION GENERATORS

3.7. A similar categorization may be applied to irradiators utilizing radiation generators, with Category I irradiators being integrally shielded units with safety interlocks[9]. Category I electron beam irradiation facilities and X ray irradiation facilities are not within the scope of this Safety Guide. Category II units are housed in shielded rooms which are kept inaccessible during operation by means of an entry control system (Figs 4 and 5).

3.8. Irradiators with radiation generators include equipment that accelerates electrons within a vacuum system. The electron beam is used to irradiate product directly or, in X ray irradiators, is directed at a target to generate X rays that irradiate product.

3.9. Category II electron beam irradiators and X ray irradiators may give rise to radiation protection issues that are not relevant for gamma irradiators, with regard to neutron radiation fields and the activation of materials. The thresholds above which these issues may be relevant are dependent upon a number of factors, such as product material and target material, but are typically only significant at energies above 10 MeV for electron beams and 5 MeV for X ray irradiators.

[9] A safety interlock is an engineered device for precluding exposure of an individual, either by preventing entry to the controlled area or by automatically removing the cause of the hazard.

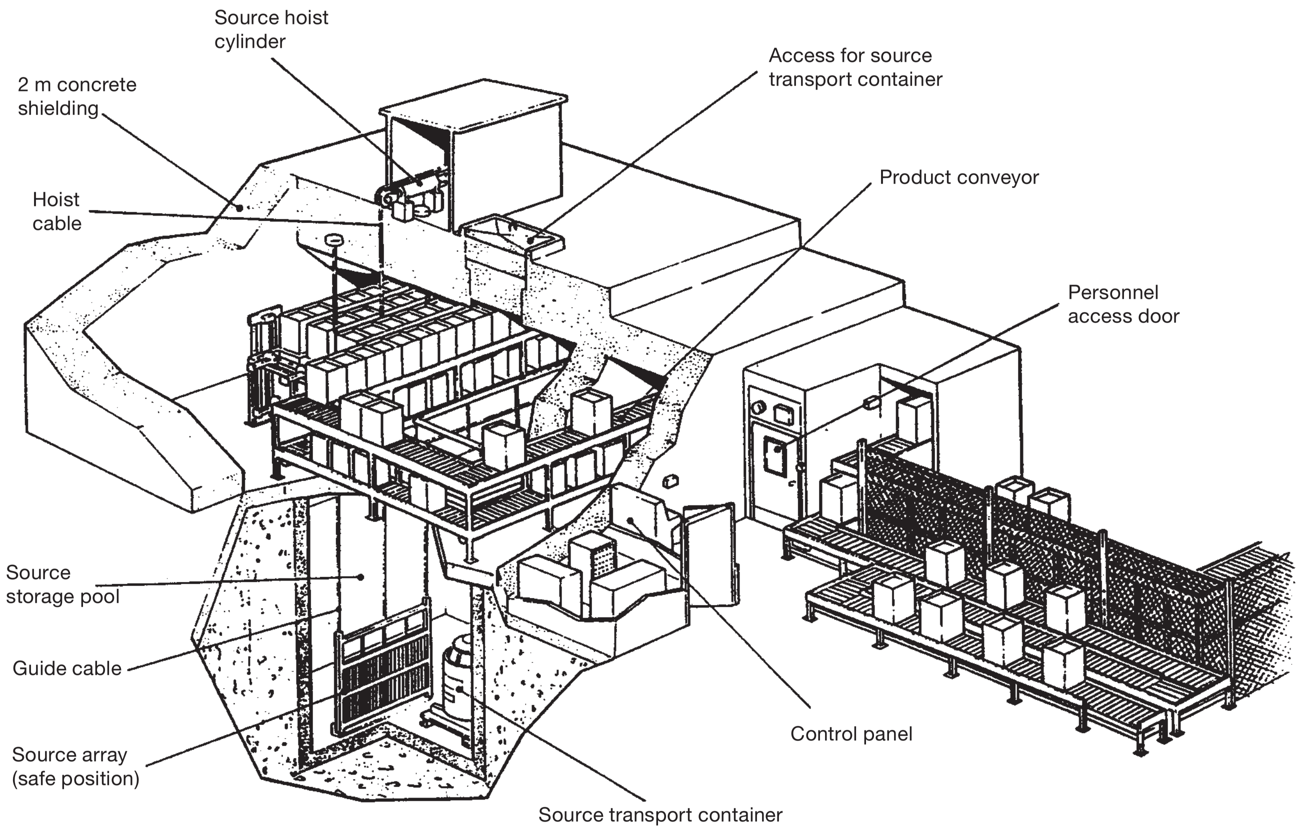

FIG. 3. Category IV gamma irradiation facility: Panoramic wet source storage irradiator.

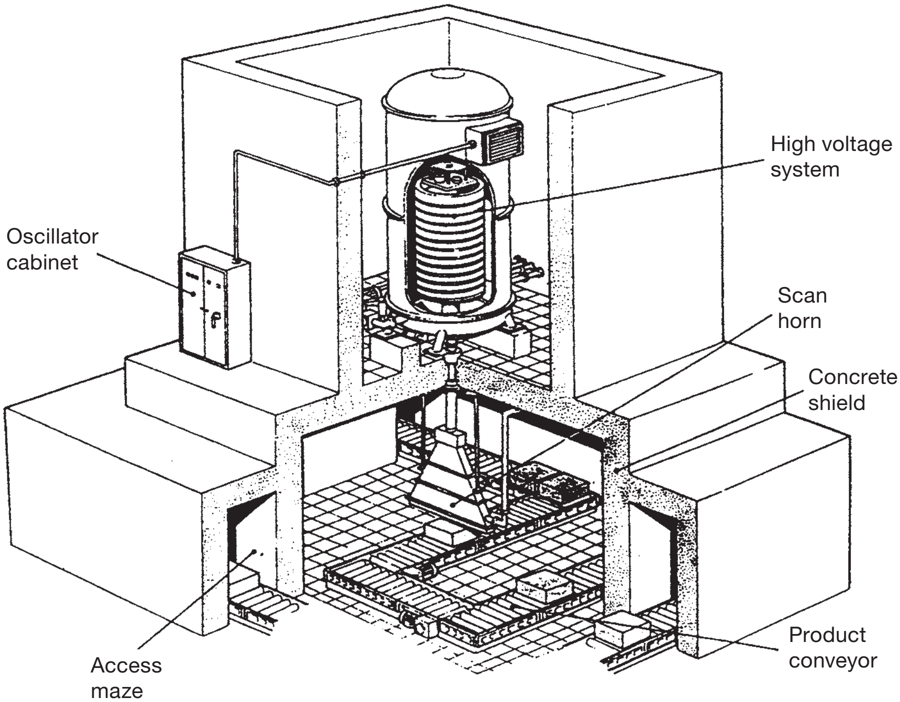

FIG. 4. Category II electron beam irradiation facility: Unit housed in shielded rooms kept inaccessible during the irradiation process.

4. PRINCIPAL ELEMENTS OF PRACTICES

NOTIFICATION AND AUTHORIZATION OF THE PRACTICE

4.1. The BSS [2] require, in paras 2.10 and 2.11, that a person or organization intending to build or operate an irradiation facility notify the regulatory body of this intention and submit an application for authorization. This application should contain information that demonstrates the safety of the practice. The type and amount of information that should be provided in the application is discussed in Ref. [6]. Specific guidance relating to the preparation of an application for the authorization of an irradiator, and its subsequent review by the regulatory body, is included in a supplement to that Safety Guide [7]. As required by the BSS [2], in paras 2.11 and 2.12, given the risks involved in the operation of an irradiator, the authorization granted by the regulatory body should take the form of a licence rather than registration.

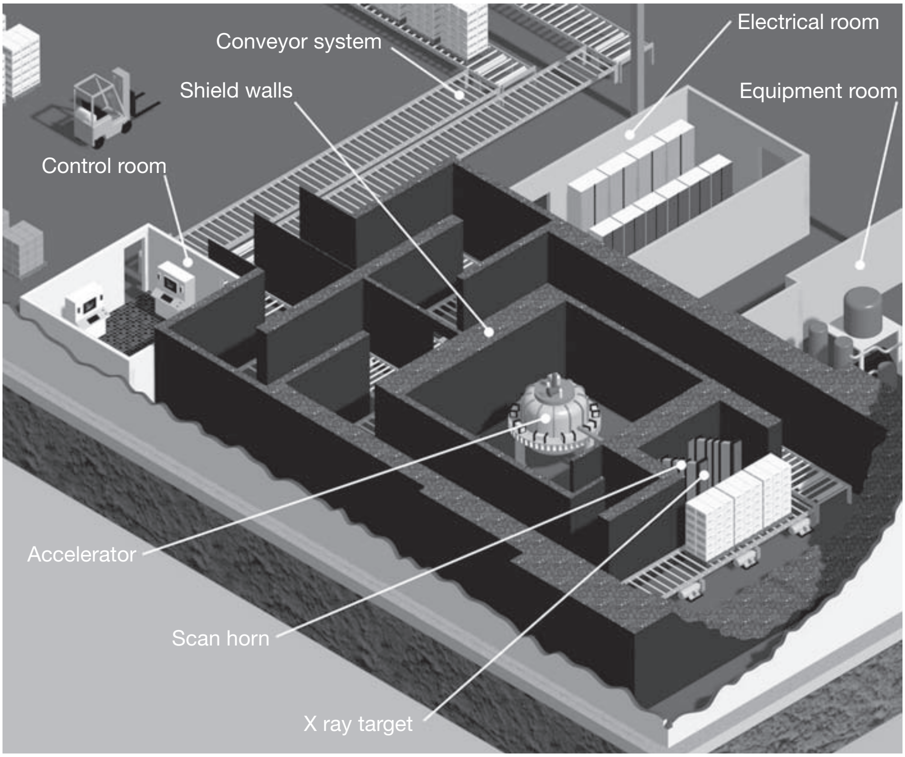

FIG. 5. Category II X ray irradiation facility: Unit housed in shielded rooms kept inaccessible during the irradiation process (courtesy of Sterigenics International).

4.2. The operating organization should obtain the approval of the regulatory body before implementing any modifications of the irradiator that may have significant implications for radiation protection. The manufacturer(s) of the irradiator and of its sources and key components should also be contacted, where appropriate, regarding proposed modifications of the irradiator (see para. 9.15).

RESPONSIBILITIES OF THE OPERATING ORGANIZATION

4.3. The operating organization's management is responsible for the operation of the irradiator and for its safety. For new facilities, the operating organization will obtain a licence from the regulatory body for the siting, design, construction, acquisition, storage and operation of the irradiator. The operating organization is responsible for the operation of the irradiator in accordance with regulatory requirements.

4.4. The operating organization of an irradiator should ensure that the facility is designed to meet the radiation safety objectives given in paras 4.13–4.16, as well as any more specific safety requirements of the regulatory body pertaining to site selection and evaluation, construction, installation, operation, maintenance and decommissioning. This should be achieved by:

- Using a qualified expert in radiation safety who is accredited according to criteria specified by the regulatory body and who is knowledgable about the safe design of irradiation facilities.
- Ensuring that the following items are provided:
  - A detailed description of the design and operation of the safety systems, including control circuit diagrams.
  - Detailed operating procedures and maintenance procedures, including the type and frequency of checks of safety and control systems, routine monitoring and radiation surveys.
  - Safety assessments using formal methods of analysis appropriate to the level of risk associated with the facility. The operating organization should also carry out a safety assessment on the basis of information provided by the supplier and the operating organization's own administrative rules.
  - Instructions and procedures to be followed in an emergency, as outlined in Section 11.

4.5. The operating organization of an irradiation facility should ensure that all documents provided by the manufacturer, supplier and installer (operating manuals, operating rules and procedures, and emergency procedures) are available in the local language and are understandable to the users.

4.6. The BSS [2], in para. IV.23, require operating organizations to ensure that information on both normal and abnormal operations significant to protection and safety is disseminated or made available, as appropriate, to the regulatory body and to manufacturers and/or suppliers, as specified by the regulatory body. This information would cover, for example, maintenance data, descriptions of events, information regarding defects in materials and equipment, weaknesses in operating procedures and corrective actions. The operating organization should ensure that any new information of this type that is known to manufacturers and suppliers is obtained from them as rapidly as possible. It may be necessary for the operating organization to periodically seek this information from the manufacturer and/or supplier, rather than relying upon them to provide it.

4.7. The operating organization of a facility should ensure that construction and installation work does not compromise the safety of the facility. On completion of the installation, or at appropriate stages during construction, the operating organization should ensure that a qualified expert[10] thoroughly and critically reviews the facility and any component part before it is commissioned. This should ensure that:

— Safety features and warning signals and alarms have been properly installed and operate correctly;
— Radiation protection for workers and members of the public and protection of the environment are adequate.

4.8. The operating organization of a facility should ensure that the constructor or installer provides it with adequate information about the proper operation, maintenance and decommissioning of the facility. The operating organization should also ensure that designers, manufacturers, constructors and installers cooperate to provide employees with the necessary theoretical and practical training to enable them to work in a safe manner.

4.9. The operating organization should permit inspection of its facilities and records by the regulatory body.

4.10. The operating organization should notify the regulatory body of any proposed modifications of the irradiator or changes to key personnel, in particular senior managers, the principal radiation protection officer, qualified experts and irradiator operators.

4.11. The operating organization should notify the regulatory body of, and should submit a plan for, the transfer or disposal of radioactive sources when they are no longer in use.

4.12. At the end of the operating lifetime of the irradiation facility, the operating organization should ensure that: buildings and equipment are free from radioactive material and contamination before disposal or resale; all radioactive

[10] The term ‘qualified expert’ is used in various places in this Safety Guide without modification. It should be noted that the individual should be a qualified expert in a field (e.g. radiation protection or design and operation of irradiation facilities) that is relevant to the issues being described.

sources are properly accounted for[11] before they are returned to the supplier or disposed of in accordance with national regulations; and any radioactive waste resulting from decontamination is disposed of in accordance with regulatory requirements.

MANAGEMENT AND ORGANIZATIONAL RESPONSIBILITIES

General

4.13. Operating organizations should provide the human and material resources necessary to ensure safe working conditions and compliance with regulatory requirements.

4.14. Operating organizations should ensure that all aspects of protection and safety are provided for in a systematic manner. To meet this objective, operating organizations should establish and maintain a radiation protection programme that includes a commitment by management to developing and promoting a safety culture that encourages a questioning and learning attitude to protection and safety, and that discourages complacency. The commitment should also include the allocation of adequate time, personnel and equipment.

Radiation protection programme

4.15. The general objective of a radiation protection programme is to discharge the management's 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 radiation risks. The radiation protection programme represents the totality of actions undertaken to achieve the stated aims of the operating organization for radiation protection and safety. Doses received by workers and members of the public should thus be kept well below the relevant dose limits specified in the BSS [2].

4.16. Application of the optimization principle should be the principal driving force behind the establishment and implementation of radiation protection programmes, including in many cases measures to prevent or reduce potential

[11] 'Accounting' in this context means physically checking that all radioactive sources are present in their intended locations. This may be undertaken by means of an appropriate radiation survey.

exposures and to mitigate the consequences of accidents. The existence of a radiation protection programme is not sufficient in itself; managers and workers should demonstrate their ongoing commitment to the programme and its objectives. Detailed guidance on establishing and maintaining a radiation protection programme that focuses on the protection of workers is provided in IAEA Safety Standards Series No. RS-G-1.1 [8].

Structure of the radiation protection programme

4.17. The radiation protection programme may include a top level policy document supported by detailed and specific procedures or 'local rules' and a comprehensive system of records. These components should consist of the following:

- A policy document specifying:
  - Objectives;
  - Responsibilities;
  - Training;
  - Safety assessment;
  - Quality management.
- Procedures and local rules covering:
  - Operation (e.g. access control, startup and shutdown procedures);
  - Maintenance and loading and unloading of radioactive sources[12];
  - Transport of radioactive sources (see footnote 12);
  - Individual monitoring;
  - Training;
  - Leakage testing of radioactive sources (see footnote 12);
  - Testing of radiation monitors;
  - Routine checks by a radiation protection officer;
  - Audits and safety assessments by a qualified expert;
  - Response to visible and audible alarms;
  - Incident reporting and investigation;
  - Emergency response.
- A system of records covering:
  - Documentation of authorization and any correspondence between the operating organization and the regulatory body;
  - Name of the authorized person responsible for the radiation protection programme;

[12] This applies for gamma irradiation facilities only.

- Safety assessment reports;
- Operation logbook;
- Routine checks of safety systems by a radiation protection officer;
- Individual doses (current and prior work history);
- Results of workplace monitoring;
- Radiation monitor test reports;
- Results of leakage tests of radioactive sources (see footnote 12);
- Inventory of radioactive sources (see footnote 12)[13];
- Records of movements of radioactive sources (see footnote 12);
- Reports on investigations of incidents and accidents;
- Audits and reviews of the radiation safety programme (by a qualified expert);
- Installation, maintenance and repair work;
- Facility modifications;
- Training provided (initial and refresher);
- Transport of radioactive sources (see footnote 12):
  - Transport documentation;
  - Contamination surveys and radiation level surveys;
- Disposal or return of radioactive sources (see footnote 12);
- Records of training, which should include the following information:
  - Name of the person who received the instruction or training;
  - Name of the institution or person who provided the instruction or training;
  - Date and duration of the instruction or training;
  - A summary or list of the topics addressed;
  - Results of examinations taken;
  - Copies of training certificates.

Safety assessment

4.18. In order to comply with the requirement in para. IV.3 of the BSS [2], a formal method of safety assessment such as probabilistic safety assessment (PSA) should be used. Examples of the application of techniques of probabilistic safety assessment to industrial irradiators are given in ICRP Publication No. 76 [9]. Guidance on methods of probabilistic safety assessment is provided in IAEA Safety Standards Series No. RS-G-1.10 [10].

[13] 'Inventorying' means conducting a campaign to physically check all radioactive sources under the responsibility of a person or organization, by specifically and uniquely identifying each individual source using appropriate means such as serial numbers.

4.19. In 2003, an IAEA coordinated research project studied the benefits and limitations of the application of techniques of probabilistic safety assessment to radiation sources. In this research project, techniques of probabilistic safety assessment were applied to a Category IV gamma irradiator. The results of this project were presented in IAEA-TECDOC-1494 [11].

4.20. The operating organization should demonstrate to the regulatory body how the design of the irradiation facility and the related operational procedures will contribute to the prevention of accidents or to the mitigation of the effects of accidents. This information should be provided in the form of a documented safety assessment describing and evaluating the predicted response of the plant to incidents (including postulated malfunctions or failures of equipment, common cause failures and human errors) and external events that could lead to accident conditions. These analyses should include consideration of combinations of such malfunctions, failures, errors and events.

4.21. Examples of issues to be examined in the safety assessment include:

- Loss of access control;
- Malfunctions and failures of structures, systems and components;
- Loss of control over the system for the movement of radioactive sources, including a source rack becoming stuck in the unshielded position (see footnote 12);
- Loss of integrity of systems or components, including shielding integrity, encapsulation of sealed sources and pool integrity (see footnote 12);
- Electrical distribution faults, from localized faults to complete loss of external energy sources;
- Failures of safety systems caused by fires within the facility;
- Failures of safety systems resulting from external causes such as storms, floods, earthquakes or explosions;
- Failures of personnel to observe proper, safe procedures (for whatever reasons);
- Breakdown of procedures for preventing access to the facility by unauthorized persons;
- Breakdown of administrative procedures, leading to unsafe practices;
- Detection of contamination;
- High radiation levels in locations where high levels would not be expected.

Verification of safety

4.22. Paragraphs 2.38–2.40 of the BSS [2] require that monitoring and measurements be conducted of the parameters necessary for the verification of compliance with the safety standards. The BSS also require that equipment used for this purpose be properly maintained, and be tested and calibrated at appropriate intervals against standards that are traceable to national or international reference standards.

4.23. Operating organizations should conduct periodic audits to verify compliance with the requirements of the regulatory body. However, the regulatory body has the overall responsibility for ensuring that practices within its jurisdiction remain in compliance with regulatory requirements. Audits that are conducted by the regulatory body when the irradiator is being commissioned, as well as at regular intervals during its operation, should be part of the verification process. General information about the inspection of radiation sources and regulatory enforcement, including examples of checklists for the inspection of industrial irradiators, are included in IAEA-TECDOC-1526 [12].

Radiation protection officer

4.24. A radiation protection officer should be a person technically competent in radiation protection matters of relevance for a given type of irradiator who is designated by the operating organization to oversee compliance with the requirements of the safety standards. Radiation protection officers play a supervisory role in assisting the operating organization in discharging its responsibilities with regard to radiation safety. A principal radiation protection officer should report directly to senior management and should have sufficient authority to discharge his/her duties.

4.25. In cases where there is a potential conflict between operational responsibilities, such as responsibilities for meeting production targets and responsibilities for radiation safety, radiation safety requirements should always take priority. At least one radiation protection officer should be available, though not necessarily physically present, at all times. In addition to a principal radiation protection officer, irradiation facilities will often have several radiation protection officers who are present at the facility during different work shifts throughout the day. The operating organization should notify the regulatory body of the appointment of radiation protection officers in accordance with regulatory requirements.

4.26. While the radiation protection officer oversees the application of the safety standards, the prime responsibility for safety remains with the operating organization. Paragraph 1.9 of the BSS [2] states that the operating organization is required to have the primary responsibility for establishing protection and safety objectives in conformity with the relevant requirements of the safety standards and to develop, implement and document a protection and safety programme. These responsibilities cannot be delegated to the radiation protection officers or the qualified expert. The duties of radiation protection officers at irradiation facilities should include the following, some of which may require consultation with, or assistance from, the qualified expert:

- Ensuring that all irradiator operators, maintenance staff, contractors and other relevant individuals and organizations are provided with copies of the operating instructions in the local language, and that they have read and understood and are complying with these instructions;
- Identifying controlled areas and supervised areas;
- Controlling access to controlled areas;
- Optimizing exposure controls and maintaining engineering features and other equipment that contributes to controlling exposure of workers and members of the public;
- Deciding whether any special restrictions are needed with regard to the exposure of female employees who might be pregnant;
- Arranging for testing of fixed radiation monitors, and for calibration and testing of radiation survey meters;
- Maintaining records of the radioactive source (see footnote 12) and relevant training and safety records;
- Performing routine radiation surveys and environmental monitoring;
- Supervising the issuing and return of personal dosimeters and reviewing dosimetry results;
- Arranging statutory tests for leakage of radioactive material (see footnote 12);
- Undertaking a programme of periodic safety checks of safety systems and warning signals and alarms, and of general conditions at the facility, as described in Section 9;
- Liaising with contractors, designers and suppliers with regard to radiation protection matters and significant changes to physical or operational aspects of the facility;
- Arranging radiation protection training for irradiator operators, maintenance staff, contractors and other staff, as appropriate;

- Ensuring the adequacy of safety assessments and contingency plans for any reasonably foreseeable incidents with consequences for radiation protection;
- Arranging periodic exercises to test the effective implementation of these contingency plans;
- Investigating any incidents including near misses at the facility such as:
  - Any of the operational parameters subject to periodic quality control being out of the normal ranges established for operational conditions;
  - Any equipment failures, accidents, errors, unusual events or circumstances that cause, or have the potential to cause, doses in excess of regulatory dose limits (e.g. failure of the radioactive source to return to the shielded position).

Irradiator operator

4.27. Irradiator operators are the workers who work most closely with a particular irradiator and who generally have day to day responsibility for its safe operation. Only qualified irradiator operators should be authorized to operate the irradiator.

4.28. A qualified irradiator operator should:

- Complete a course of training that is acceptable to the regulatory body;
- Be knowledgable about the basic design, operation and preventive maintenance of the irradiator and the written procedures for routine and emergency operation of the irradiator;
- Be knowledgable about the dose rate at all areas around the irradiator;
- Be knowledgable about features that contribute to the security of radioactive sources, such as locks, posted signs, warning lights, visible and audible signals and safety interlock systems;
- Be knowledgable about the radiation detection instruments and the requirements for individual monitoring;
- Be able to operate the irradiator in a safe manner and to maintain the required operation logs and records;
- Be knowledgable about the overall organizational structure pertaining to management of the irradiator, including specific delegations of authority and responsibility for operation of the irradiator.

Other workers

4.29. In addition to qualified irradiator operators, other workers should be employed by the operating organization to undertake a range of routine activities. These include moving product in and out of the radiation room, housekeeping duties with potential implications for radiation safety and routine maintenance activities. The competence of these workers to perform their duties in a safe manner should be verified by a radiation protection officer.

4.30. There may be occasions when other workers perform services at a facility on a temporary basis; for example, during the loading and unloading of radioactive sources, or in response to mechanical malfunctions (see footnote 12). Safety in these operations depends, in part, on cooperation between those responsible for radiation protection at the facility and those performing services. In many cases, services will be performed by the radioactive source supplier or the irradiator designer. Specific authorization may be granted to outside organizations such as the irradiator designer or the radioactive source manufacturer to perform specific activities that are outside the scope of the normal operation of irradiators. Ultimately, however, responsibility for safety while radioactive sources are on site rests with the operating organization.

Qualified experts

4.31. A qualified expert is an individual who is duly recognized, by virtue of certification by appropriate boards or societies, professional licences or academic qualifications, and experience, as having expertise in a relevant field of specialization. Such fields include medical physics, radiation protection, occupational health, fire safety, quality assurance and any relevant engineering or safety specialty.

4.32. The operating organization may identify one or more qualified experts to provide advice on various matters concerning radiation safety in the design and operation of the facility. A qualified expert need not be a full time employee of the operating organization but could be employed on a part-time or an ad hoc basis. However, arrangements should be made for the advice of a qualified expert to be available when necessary. As with the radiation protection officer, the operating organization cannot delegate its responsibility for safety to a qualified expert.

4.33. A qualified expert should be experienced in radiation protection matters and should have:

— Theoretical training that includes training in the properties of radiation as used in the irradiator;
— A thorough knowledge of the hazards associated with the radiation present and the ways in which these hazards can be controlled and minimized;
— An understanding and detailed knowledge of the working practices used in the facility, as well as a general knowledge of the working practices in other similar facilities;
— A detailed working knowledge of all regulatory provisions, relevant codes of practice and protection standards, guidance materials and other information necessary for giving advice in connection with the work with radiation undertaken by the operating organization;
— An awareness of legislation that could affect the work with radiation on which the qualified expert gives advice;
— The ability to give advice so that the operating organization can comply with regulations and follow good radiation protection practices;
— The ability to communicate with workers and their representatives;
— The ability to keep up to date with developments in the use of radiation in the field in which the qualified expert gives advice and with developments in radiation protection.

4.34. The operating organization should provide the qualified expert with the information and resources necessary for the expert to work effectively. The information should include a clear statement of the scope of the advice that the expert is expected to give.

4.35. The operating organization may consult the qualified expert on a wide range of issues relating to radiation safety, including:

— Optimization of protection and safety;
— Maintenance of engineering features and other equipment;
— Dosimetry and radiation monitoring;
— Investigation of abnormally high exposures and overexposures;
— Staff training;
— Safety assessment and contingency arrangements;
— Examination of any plans for a new plant or premises, or for modifications of an existing plant or premises;

— Independent audits of radiation protection systems;
— Quality management;
— Performance of emergency drills;
— Assistance following an emergency.

4.36. The BSS [2], in para. 2.31, require that qualified experts be identified and made available for providing advice on application of the safety standards.

4.37. Paragraph 2.32 of the BSS [2] states that registrants and licensees shall inform the regulatory body of their arrangements to make available the expertise necessary to provide advice on application of the safety standards. The information provided shall include the scope of the functions of any qualified experts identified.

LOCAL RULES

4.38. The operating organization should ensure that operational instructions are fully understood by the qualified irradiator operators and other workers. Operational instructions should, at a minimum, include:

— A description of the nature of the hazards posed by the facility and the safety features used to minimize the risks.
— A reference to the existence and the location of the written emergency procedures.
— A description of the functions, duties and responsibilities with regard to radiation safety of key individuals within the operating organization, including the qualified expert and radiation protection officers.
— The method of implementing the operating instructions and ensuring that the facility is being operated safely. This should include:
  • A description and schedule of the inspections and test procedures for ensuring that all safety interlock systems and components associated with the irradiator are functioning properly. Each safety item and the appropriate test, check and inspection for it should be specified.
  • A requirement for the operating procedures to be available at the control console and for the emergency procedures to be conspicuously posted.
— The method of ensuring that persons entering the controlled area are wearing appropriate radiation monitoring devices and that the results of the monitoring are recorded.

— The method of controlling access to the controlled area and ensuring that only qualified irradiator operators can use the irradiator at appropriate times. This can involve controlling access to the operating console keys and the keys to the door of the room containing the operating console, or other active methods of preventing access. Operating console keys should be controlled to ensure that the qualified irradiator operator who is entering the radiation room has the only key in the operating area that could initiate startup or provide access. Spare keys should be kept in a secure location away from the vicinity of the control room, such as in a safe under the control of a senior manager.
— Written instructions covering actions to be taken in the event of malfunctions. These instructions should identify individuals to be notified in the event of a malfunction and should provide a general outline of the corrective actions to be taken. Necessary corrective actions may involve technical aspects of safety systems of the irradiator that are outside the scope of the normal maintenance procedures; they may also involve the manipulation of tools and equipment that could potentially lead to radiation overexposures of personnel. Any such corrective actions should be attempted only by persons specifically trained and authorized to perform such work, or by those who are under the supervision of such persons. Following such corrective action, persons should never enter the radiation room alone. The safe operation of a facility will depend on the qualified irradiator operators' following clearly defined procedures laid down by the manufacturer or the supplier and approved by the regulatory body.
— Written instructions to ensure that the irradiator is maintained as prescribed by the manufacturer, with particular attention paid to ensuring that all components of the product positioning system[14], product boxes and carriers continue to meet design specifications. For example, it should be ensured that the correct product boxes or carriers are used and that they are maintained in a condition that will not cause an irradiator malfunction.
— Written instructions to require that the irradiator operator carry a portable radiation survey meter when entering the radiation room. A check source should be used to verify that the survey meter is operating before each entry into the room. A similar spare survey meter should be available for use when the calibration or repair of a monitor is necessary.

[14] The product positioning system is the means by which the product is conveyed around the irradiation room and past the radiation source to be irradiated.

— Written instructions to require that the irradiator operator check that all visual indicators of the plant conditions show that it is safe to enter the radiation room. In addition, procedures should be established for the continuous monitoring of radiation levels with a portable radiation survey meter when a person enters the radiation room.

TRAINING AND EDUCATION

4.39. Training and education requirements for workers should be commensurate with the duties and responsibilities of their jobs with respect to the operation of the irradiator. Categories of workers that are trained usually include:

— Managers having line responsibility;
— Radiation protection officers;
— Qualified irradiator operators;
— Other workers who may be required to enter controlled areas to perform duties, such as for the purposes of product movement, routine maintenance and housekeeping.

4.40. People who may be required to render assistance in emergencies should be given training to familiarize them with the facility and the hazards that could arise from its operation. This should include personnel from fire and police services and medical organizations.

4.41. Operating organizations should ensure that women who may enter controlled areas or supervised areas are provided with information regarding the risks to an embryo or fetus from exposure to radiation and the importance of notifying their employer as soon as pregnancy is suspected.

4.42. A radiation protection officer and a qualified expert should provide advice on staff training needs and on how those needs may best be satisfied. In many cases, a radiation protection officer can provide much of the necessary training.

4.43. The BSS [2], in para. I.4(h), require employers and operating organizations to ensure, for all workers who are or who could be subject to occupational exposures, that “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”.

4.44. Workers who could be subject to occupational exposures should be trained in the following topics:

— The nature of radiation;
— Health hazards due to exposure to radiation;
— Basic principles and methods of protection (e.g. time, distance, shielding);
— Measurement of radiation fields and the units of measurement;
— Actions to be taken in response to visible and audible warning signals and alarms;
— Actions to be taken in emergencies.

4.45. The BSS [2], in para. 2.30(a), require operating organizations to ensure that "all personnel on whom protection and safety depend be appropriately trained and qualified so that they understand their responsibilities and perform their duties with appropriate judgement and according to defined procedures".

4.46. In addition to the topics described above, operating organizations should also ensure that qualified irradiator operators and radiation protection officers know about and understand the following:

— The functioning of the irradiator, including safety features;
— Applicable regulations;
— Licence conditions;
— The radiation protection programme;
— Requirements for individual monitoring and workplace monitoring;
— Requirements for accountability for and control and security of radioactive sources;
— Hazards identified in the safety assessment;
— Local rules;
— Procedures to be followed in emergencies;
— Case histories of accidents or problems involving irradiators.

4.47. The operating organization should prepare and maintain records of the initial and ongoing training of all workers. These training records should include the following information:

— Name of the person who received the instruction or training;
— Name of the institution or person who provided the instruction or training;
— Date and duration of the instruction or training;
— A summary or list of the topics addressed;

— Results of examinations taken;
— Copies of training certificates.

Training records should be made available to the recipients of the training, especially in the event of a person’s moving to another employer.

5. INDIVIDUAL MONITORING OF WORKERS

INDIVIDUAL DOSE ASSESSMENT AND RECORD KEEPING

5.1. Paragraphs I.33 and I.34 of the BSS [2] state respectively:

> “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.”
>
> “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.”

5.2. For irradiation facilities, controlled areas should consist of the following:

— Underwater gamma irradiators (Category III): the room in which the irradiator is housed;
— Panoramic gamma irradiators (Categories II and IV): the radiation room and roof of the radiation room;
— Electron beam irradiators (Category II) and X ray irradiators (Category II): the radiation room.

5.3. The following areas should be designated as supervised areas, unless circumstances warrant their designation as controlled areas:

— Underwater gamma irradiators (Category III): control room;
— Panoramic gamma irradiators (Categories II and IV): product entry and exit areas and service areas such as where the source rack hoist is located, water treatment rooms and control room;
— Electron beam irradiators (Category II) and X ray irradiators (Category II): product entry and exit areas, service areas, power supply room and control room.

5.4. The designation of these areas should be reviewed regularly, and may be changed or extended during initial installation, maintenance and operations for the loading and unloading of radioactive sources.

5.5. A programme for individual monitoring of external radiation exposure is intended to demonstrate that worker exposures are being controlled, to provide information for the optimization of protection and to verify the adequacy of work procedures. Guidance on establishing monitoring programmes for external exposure, selection of appropriate dosimeters, interpretation of results, record keeping and quality management is given in IAEA Safety Standards Series No. RS-G-1.3 [13].

5.6. Irradiator operators, radiation protection officers and maintenance staff who routinely enter controlled areas should be subject to individual dose monitoring. These individuals should wear whole body monitors (e.g. a film badge, thermoluminescent dosimeter, optically stimulated luminescent dosimeter).

5.7. The tools and procedures for individual monitoring of exposure of workers, including the type of dosimeter required and the necessary frequency of replacement, should be chosen in consultation with a radiation protection officer or qualified expert, in accordance with the requirements of the regulatory body. The dosimeters should be provided and processed by a laboratory or company that has been authorized by the regulatory body and is traceable to a standards dosimetry laboratory approved by the regulatory body.

5.8. The operating organization should make arrangements to ensure that dose records are maintained for each worker in the manner specified in regulatory requirements. Operating organizations should ensure that personal dose records are provided to workers upon termination of their employment and are available to individuals at other times.

5.9. Operating organizations should prepare procedures describing the way in which individual dosimeters are to be administered, and these procedures should include the following:

- Ordering and receipt of dosimeters from the dosimetry laboratory;
- Distribution of dosimeters to monitored workers;
- Collection and dispatch of dosimeters to the dosimetry laboratory for processing;
- Review and maintenance of dose records.

5.10. Operating organizations should provide suitable storage facilities for personal dosimeters that are not in use; these storage facilities should protect the dosimeters from inadvertent exposure to radiation and from adverse environmental conditions such as temperature extremes and/or humidity. Personal dosimeters should not be stored close to any area where dose rates are above normal background levels. Dosimeters should not be put through mail inspection systems that utilize X rays.

5.11. Monitored workers should be required to take good care of their dosimeters, and to take precautions to protect them from loss, theft, tampering or damage and from inadvertent exposure to radiation. Workers should return dosimeters promptly at the end of the specified wearing period. Workers should inform a radiation protection officer without delay if a dosimeter is missing or damaged, or if it has been exposed to radiation when it was not being worn.

5.12. If a dosimeter is lost, operating organizations should take all reasonable steps to recover it. If the dosimeter cannot be located, operating organizations should carry out an investigation and should prepare a report that includes an estimate of the dose received by the worker for the relevant period of time. In some Member States, the approval of regulatory bodies may be required prior to the entry of such estimates into a person's dose record.

INVESTIGATION OF DOSES

5.13. The operating organization should instruct workers to notify a radiation protection officer immediately if they know or suspect that they have been exposed to high level radiation. If the individual concerned was wearing a personal dosimeter, it should be sent to the dosimetry laboratory immediately, and the laboratory should be informed of the urgency of the case.

5.14. A radiation protection officer should inspect the results of personal dosimeter readings promptly to determine whether any unexpectedly high doses have been reported and to determine whether individuals are keeping their doses as low as reasonably achievable, taking into account their workload and any dose constraints.

5.15. The operating organization should conduct a formal investigation, as required by the regulatory body, whenever the recorded dose exceeds the investigation level. The investigation should be initiated as soon as possible following the event, and a written report should be prepared concerning its cause. This report should include a determination or verification of any doses received, details of corrective or mitigating actions, and instructions or recommendations on how to avoid a recurrence.

5.16. The report should be provided to all concerned parties within the appropriate time frame as required by the regulatory body.

6. WORKPLACE MONITORING

MONITORING OF THE WORKPLACE

6.1. The BSS [2] require, in paras I.37–I.39, 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 body], of a qualified expert and a radiation protection officer.
>
> "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.

“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.”

6.2. To assess and control occupational exposure, it is necessary to know the dose equivalent rates in the various working areas. Workplace radiation surveys are primarily intended to provide information on dose rates within these areas. This information will be used to designate the area as a controlled area or a supervised area and to make decisions about its occupancy.

RADIATION SURVEY METERS AND RADIATION MONITORS

6.3. Guidance on the selection of the proper radiation survey instrument for a given application is provided in IAEA Safety Standards Series No. RS-G-1.3 [13]. Guidance is also given in an IAEA Practical Radiation Technical Manual on Workplace Monitoring for Radiation and Contamination [14].

6.4. For portable radiation survey meters, general criteria include portability (e.g. weight, size, physical configuration), ruggedness, ease of use and reading, ease of servicing and reliability. Appropriate portable X ray and gamma radiation survey meters should be provided. At electron beam irradiation facilities operating above 10 MeV and at X ray facilities operating above 5 MeV, monitoring for neutrons may also be required. The survey meters used should be capable of clearly indicating the dose rates encountered during normal operation of the irradiator and should have a satisfactory overload performance. It should be noted that some ionization chambers might also respond to radiofrequency radiation, and could possibly give false readings in surveys around accelerator facilities.

6.5. Some radiation survey meters using a Geiger–Müller detector, particularly older instruments, give a zero reading when the Geiger–Müller detector has saturated. This has been a contributory factor where individuals have entered areas with high radiation levels believing that the zero reading on the survey meter indicated a safe condition. Any survey meter used for measurements of the external radiation level at an irradiator should be of a type that does not read zero on saturation. This is particularly important for those instruments carried into the radiation room to verify that the radioactive source is fully shielded.

6.6. In general, the following observations apply to instrument selection for an irradiation facility:

— Solid state detectors, particularly sodium iodide detectors, are appropriate for detecting low radiation levels such as might be found when monitoring the water of the source storage pool for contamination (see footnote 12). However, sodium iodide detectors are generally inappropriate for dose rate measurements, owing largely to their high energy dependence.
— Pancake Geiger–Müller detectors are designed for beta response and are appropriate for use in contamination surveys. However, the low efficiency of pancake Geiger–Müller detectors for gamma radiation makes them unsuitable for dose rate measurements, such as in irradiator shield surveys.
— Side window Geiger–Müller detectors are generally appropriate for dose rate measurements, but their relative insensitivity to beta radiation makes them unsuitable for contamination surveys.
— Survey meters using ionization chambers and energy compensated Geiger–Müller detectors are appropriate for dose rate measurements, but they tend to be less sensitive than side window Geiger–Müller detectors.

6.7. Irradiation facilities also use radiation monitors that are fixed rather than portable. Specifically, the applications for fixed instruments are as radiation room monitors and contamination monitors for storage pool water (see footnote 12). These instruments are fixed in place and are not used for radiation surveys. Instead, these devices should be used as ‘pass–fail’ indicators. That is, if the radiation level reaches a preset point, the instrument triggers an alarm condition. In this application, exposure rates and contamination levels are not quantified.

6.8. The criteria for selecting fixed radiation monitors are similar to the criteria for selecting portable monitors. However, there are additional considerations in selecting fixed monitors:

— *Saturation level*. Radiation room monitors are designed to detect high radiation levels if an accident occurs (e.g. high radiation levels when the radioactive sources are expected to be in the fully shielded position or the electron beam is expected to be switched off). Other fixed radiation monitors are designed to detect high radiation levels where product exits the radiation room (see footnote 12), a possible indication that radioactive material has become dislodged and is being carried out of the radiation room. In such situations, high radiation levels under fault conditions can saturate and possibly damage the detector to the extent that the instrument is rendered inoperable. Selection of a detector for these applications should include consideration of the radiation level at which the detector will saturate and the potential effects on the monitoring devices and safety systems should the fault condition occur. Note that if the instrument fails in such conditions, it does not necessarily mean that the particular detector is inappropriate for this use. If the system is designed to 'fail safe', so that a failure of the detector causes the same result as a high reading (i.e. denies access to the radiation room), the instrument can achieve its purpose even though the detector is damaged.

— *Sensitivity of the pool water contamination monitor.* Monitoring storage pool water for contamination (see footnote 12) necessitates that a sensitive instrument be used to detect contamination at the lowest practicable level to minimize the potential spread of contamination. Typically, solid state detectors, particularly sodium iodide detectors, are used for this purpose. In considering the sensitivity necessary, the design of the pool water monitoring system should be considered. If the water is being collected and monitored, more sensitive instruments, such as a 5.1 cm × 5.1 cm (2 in × 2 in) sodium iodide detector, should be required. If pool water is being evaluated for contamination at monitoring points in the water treatment system where contamination would be expected to accumulate, a less sensitive detector such as a 2.54 cm × 2.54 cm (1 in × 1 in) sodium iodide detector may be suitable.

MAINTENANCE AND CALIBRATION

6.9. Portable radiation survey meters should be calibrated before their first use, after repair and at intervals as specified in regulatory requirements. The pre-use test should include a test of the instrument's overload performance; that is, the instrument should be tested to verify that it will operate correctly up to the maximum foreseeable dose rate.

6.10. Following calibration, a sticker should be attached to the instrument to provide information, including the name of the organization performing the test, the test certificate number and the date of the test or the date when the next test is due, as appropriate. Tests should be carried out by an organization that maintains reference radiation fields traceable to a national standards body.

6.11. Fixed radiation monitoring instruments are not calibrated in the same sense as radiation survey meters. Since their operation is ‘pass–fail’, fixed instruments should be subject to periodic operational testing to ensure that they retain the capability to respond to relevant radiation levels. For example, check sources can be used on a monthly basis to verify that the radiation room monitor and pool water contamination monitor (see footnote 12) respond appropriately. In some applications, such as the use of a single channel analyser for pool water contamination monitoring, the instrument should be calibrated periodically to ensure that the detector voltage and window settings are still applicable.

6.12. Further information on the establishment and operation of calibration facilities for radiation survey instruments and recommended calibration procedures is provided in Safety Reports Series No. 16 [15].

USE OF RADIATION SURVEY METERS

6.13. Radiation survey meters are used to evaluate radiological conditions in the workplace, particularly in the following situations:

— *Shield survey.* Before operation of the facility is started, a radiation survey of the area outside the shielding of the radiation room should be performed, with the radioactive sources in the exposed position for a panoramic irradiator or with the electron beam at full power for an electron beam irradiator. Additional surveys of the area outside the shielding should be performed at intervals not exceeding three years, and before the resumption of operations following the introduction of new radioactive sources or changes in the orientation, energy or power level of the electron beam. Any modification of the structure of the radiation room shielding that might increase the dose rate also necessitates an additional survey.

— *Storage pool or storage container surveys.* For gamma irradiators, an initial radiation survey of the area above the source storage pool or the dry source storage container should be performed. The survey should be conducted after the radioactive sources have been loaded but before operation of the facility is started.

— *Post-shutdown radiation level surveys.* Dose rates may be temporarily elevated at electron beam irradiation facilities and X ray irradiation facilities even after the facility has been shut down, owing to dark current[15] and the presence of activation products in the accelerator, the shielding and ancillary process equipment (e.g. the beam stop or the product positioning system). Radiation level surveys should be performed in these areas before personnel are allowed to enter.

— *Contamination surveys.* The purpose of contamination surveys is to detect contamination resulting from activation products at electron beam facilities and X ray facilities so as to prevent its spread. Contamination surveys should be performed in accordance with industry standards. For surveys whose results are to be recorded and compared with the results of previous or future surveys, consistency in the survey procedure should be ensured.

In the event of any apparent change in contamination levels that cannot be attributed to known causes, an evaluation should be performed to determine the cause. Such an evaluation may include:

— Verifying that the survey instrumentation is functioning properly;
— Repeating the survey to verify the apparent change in contamination levels;
— Performing more frequent surveys;
— Consulting with the supplier of the radioactive source.

6.14. Surveys should be undertaken at positions around the facility and at intervals as advised by a qualified expert or a radiation protection officer. Such surveys should be carried out to confirm the status of controlled areas and supervised areas and to indicate any failure in the control of the radiation source.

6.15. An irradiator operator should make the initial entry to the radiation room, using a portable radiation survey meter to determine the ambient radiation levels. The portable meter should be tested for proper functioning prior to each entry into the radiation room by using a check source (e.g. 1×10^4 Bq (0.27 μCi) of caesium-137) located near the radiation room door.

[15] 'Dark current' refers to a condition in which an accelerator generates radiation when there is no current to the cathode but the accelerating voltage (i.e. a high voltage) is still applied. Electrons may still be emitted from the cold cathode and accelerated, resulting in an electron beam even though there is no current to the cathode.

6.16. When visitors are permitted to enter the radiation room, they should be issued with a personal dosimeter. The qualified irradiator operator who has surveyed the area immediately prior to the visit should escort all visitors.

RECORDS OF RADIATION SURVEYS

6.17. The BSS [2] state, in para. I.40, that:

> "Registrants and licensees, in co-operation with employers if appropriate, shall keep appropriate records of the findings of the workplace monitoring programme which shall be made available to workers, where appropriate through their representatives."

6.18. Reports on radiation levels should include the following information:

- Survey date;
- Irradiator identification (manufacturer, model number and serial number);
- Irradiator location;
- Information on the irradiator's radiation source (i.e. X rays or electron beam) and on the source intensity in the case of radiation generators or the calculated activity and the radionuclide used in the case of gamma facilities;
- Information on the survey instrument (manufacturer, model number and serial number);
- Calibration date of the survey instrument;
- Correction factors, background subtraction, conversions or other calculations for the survey instrument if used;
- Name of the person performing the survey;
- Radiation levels and the corresponding locations outside the shield both when the radiation source is in use and when either the radioactive source is fully shielded or the X ray or electron beam is shut off;
- Radiation levels and the corresponding locations inside the radiation room when either the radioactive source is fully shielded or the X ray or electron beam is shut off;
- Any actions taken on the basis of information yielded by the the survey.

6.19. The operating organization should maintain records of contamination at the facility. These records should be made available for inspection by the regulatory body. In general, these surveys should be performed routinely only at X ray and gamma irradiation facilities where neutron fields could give rise to activation products.

6.20. Contamination reports should include the following information:

— Survey date;
— Irradiator identification (manufacturer, model number and serial number);
— Irradiator location;
— Information on the irradiator's radiation source (i.e. X rays or electron beam) and on the source intensity in the case of machine produced sources or the calculated activity and the radionuclide used in the case of gamma facilities;
— Information on the survey instrument (manufacturer, model number and serial number);
— Calibration date of the survey instrument;
— Correction factors, background subtraction, conversions or other calculations for the survey instrument if used;
— Name of the person performing the survey and/or analysis;
— Contamination levels and the corresponding locations;
— Cause of the contamination, if known;
— Any actions taken on the basis of the information yielded by the survey.

7. CONTROL OVER RADIOACTIVE SOURCES

7.1. The BSS [2], in para. 2.34, require that:

"Sources shall be kept secure so as to prevent theft or damage and to prevent any unauthorized legal person from carrying out any of the actions specified in the General Obligations for practices of the [BSS] (see paras 2.7–2.9), by ensuring that:

(a) control of a source not be relinquished without compliance with all relevant requirements specified in the registration or licence and without immediate communication to the [regulatory body], and when applicable to the relevant Sponsoring Organization, of information regarding any decontrolled, lost, stolen or missing source;
(b) a source not be transferred unless the receiver possesses a valid authorization…."

7.2. Internationally endorsed recommendations to States on the safety and security of Category 1, 2 and 3 sources are given in the Code of Conduct on the Safety and Security of Radioactive Sources [16].

7.3. The primary goal of radiation safety at irradiation facilities is to control exposure to radiation emitted by radiation sources. This should be accomplished by means of the use of shielding to attenuate radiation and the control of access by means of the use of physical barriers, engineered safety systems and the implementation of procedures. The safety aspects and the security aspects of the control of radioactive sources are interrelated, and many of the measures designed to enhance one will also enhance the other.

7.4. For this reason, many of the measures described in this Safety Guide, for example, in Section 4 (on local rules, procedures and duties of personnel concerning the control of access to controlled areas) and Section 8 (on radiation shields, doors, safety interlocks, fixed radiation monitors and access keys), that are intended primarily to limit exposure to radiation will also contribute to the security of radioactive sources. For radioactive sources that are in use, the provisions in this Safety Guide for controlling exposures arising from radioactive sources should be sufficient to ensure their control with respect to inadvertent or unauthorized breaches in security that are not malicious in nature. Further guidance regarding the security of radioactive sources is provided in IAEA Nuclear Security Series No. 11 [17].

7.5. There are special concerns regarding the security of radioactive sources that are not in use. The level of control applied to radioactive sources that are stored temporarily in transport packaging or other shielded containers should not be less than the level of control over sources in use. Under certain circumstances, disused radioactive sources that are present at an irradiation facility may be considered vulnerable sources. The storage of disused radioactive sources at a facility that is no longer in operation is a special case because personnel may no longer be present at the facility on a regular basis. Provision should be made in which the intermittent presence of personnel is taken into account to ensure that such disused radioactive sources are kept secure. In all cases involving disused radioactive sources, careful consideration should be given to moving the disused sources to a storage facility or disposal facility, or to another authorized recipient such as the manufacturer.

7.6. The BSS [2] require that operating organizations ensure that “a source not be transferred unless the receiver possesses a valid authorization” (para. 2.34(b)). Before transferring a radioactive source to another entity, the operating organization should verify that the intended recipient possesses a valid authorization to possess the sources. When radioactive sources are transferred between States, the relevant recommendations of the Code of Conduct on the Safety and Security of Radioactive Sources [16] and the supporting Guidance on the Import and Export of Radioactive Sources [18] should be followed.

7.7. Lost, stolen or missing radioactive sources should be reported to the regulatory body in accordance with regulatory requirements.

8. IRRADIATOR DESIGN

8.1. Irradiation facilities should be designed to meet the requirements established in paras 2.24 and 2.25 of the BSS [2], which state that protection and safety are required to 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. Requirements that apply to the design of irradiation facilities and their radiation sources are found in the Principal Requirements of the BSS, on security of radioactive sources (para. 2.34), defence in depth (para. 2.35) and good engineering practice (para. 2.36). The responsibilities of the operating organization and suppliers with regard to the design of irradiation facilities are specified in paras IV.8– IV.14 of the BSS. Specific recommendations concerning the application of the requirements of the BSS to the design of irradiation facilities are provided in the remainder of Section 8 of this Safety Guide.

GAMMA, ELECTRON AND X RAY IRRADIATORS

Internal design

8.2. All equipment inside the radiation room of an irradiation facility, including wiring, electrical equipment, notices and lighting, should be selected so as to minimize failure due to prolonged exposure to radiation.

Product positioning system

8.3. Malfunctioning of the product positioning system can dislodge or damage the radiation source, resulting in a radiation hazard. The product conveyor mechanism should be monitored for correct operation, and any malfunction should cause the radioactive source rack to return automatically to the fully shielded position or cause the electron beam to be switched off.

Product movement timer

8.4. A timer should be used to monitor movement of the product past the radiation source. If the product fails to move in the predetermined time interval, the source rack should automatically return to the fully shielded position or the electron beam should be switched off, the product positioning system should stop, and visible and audible signals should be generated to alert the irradiator operator to the malfunction. This feature helps to prevent overheating of the product, which could possibly lead to a fire.

Shielding

8.5. Direct radiation exposure of workers and members of the public due to the operation of irradiation facilities should be attenuated to optimized levels by the use of appropriate shielding. Concrete is often used to construct the radiation room shield, but other materials such as earth fill, steel and lead may also be used in its construction. The shielding properties of particular materials are well established [19–25], but experience from existing irradiation facilities should be taken into account. The shielding should provide adequate reductions in radiation levels to keep doses within the dose constraints established or agreed to by the regulatory body.

8.6. Penetrations of the shield will be necessary for entry and exit ports for personnel and product, and for the ventilation system and other ducting. These penetrations pose particular problems for the shielding designer, who should ensure both that there is no direct radiation leakage path and that the use of maze entrances and shield plugs is sufficient to reduce external radiation fields to optimized levels. When sufficient reduction in doses cannot be achieved, access to the area should be restricted. Care should be taken to ensure that all significant radiation paths are fully evaluated, including, in the case of gamma irradiation facilities, those that arise during the transit of the radioactive source from its shielded position to its operating position. Where practical, all tubes, pipes and conduits should take a curved or stepped path through the shielding material to reduce external radiation levels.

8.7. In irradiator systems that utilize activity levels in excess of 1.85×10^{17} Bq (5 million Ci) of cobalt-60 or equivalent, the energy absorbed in the shield walls and the resulting maximum shield temperatures should be evaluated. Maximum temperatures within standard concrete shields should not exceed 315°C (600°F) [26]. The energy absorbed in dry source storage containers due to heat produced by the absorption of gamma radiation should also be evaluated to ensure that the integrity of the shielding is not compromised. Also, the maximum storage temperature of sealed sources should not exceed the manufacturer's specification.

8.8. Although general guidance on shielding is given in this Safety Guide and in the publications referenced in it, all shielding calculations carried out for the purposes of design should be undertaken by specialists.

8.9. Once the shield has been designed, no subsequent changes should be made unless they have been carefully considered and agreed to by the regulatory body.

Access to the radiation source and safety interlock systems

8.10. Particular attention should be paid to the accessibility of the radiation room in Category II and IV gamma irradiation facilities, Category II electron beam facilities and X ray facilities. The design of these facilities should be such that persons cannot gain access to the radiation room while the radioactive source is in the exposed position or while the electron beam is energized. Such control of access relies heavily on the use of safety interlock systems.

8.11. Access by personnel to the radiation room following an irradiation, securing of the radiation room prior to initiating an irradiation, and irradiation start procedures should incorporate a series of sequential safety interlocks and controls. Such safety interlocks and controls should be designed such that any attempt to preempt the controls or to apply them out of sequence will automatically prevent the intended operation.

8.12. The following is an example of such sequential control operations:

— Personnel access:
  (1) Ensure that the radiation room access controls are energized at the control console.

(2) Verify that the radiation room monitor is functioning properly and verify that the radiation level in the room is acceptable.
(3) Open the access door using the multipurpose key.
(4) On entry to the radiation room, continuously monitor the radiation levels with a portable radiation survey meter.

— Sequence for securing the radiation room prior to initiating irradiation:
(1) Ensure that the radiation room is free of personnel and that the irradiator mechanisms are operational.
(2) Actuate the safety delay timer.
(3) Actuate the control inside the radiation room, if different from the safety delay timer.
(4) Close and lock the radiation room access door.

— Start procedure for irradiation: Actuate the source rack hoist mechanism at the control console with the multipurpose key before the preset safety delay time period has elapsed.

The irradiator is now in full operation, and it should not be possible to remove the multipurpose key without stopping irradiator operation.

Safety interlock for the personnel access door

8.13. The personnel access door to the radiation room should be closed and secured before the irradiation process can begin. The safety interlocks for the access door should be integrated into the master control system so that violation of the safety interlock system or use of the door will cause irradiation to be automatically terminated. Any violation or failure of the safety interlock for the access door should actuate visible and audible alarms. Opening the personnel access door should disable the means of producing radiation[16].

Backup access control — Personnel entry

8.14. In addition to the safety interlock for the personnel access door, each entrance to the radiation room should have an independent backup control to detect the entry of personnel either while the radioactive source is in the unshielded position or while the electron beam is energized. Examples of backup access controls are pressure mats, light beam interruption detectors (‘photo eyes’)

[16] ‘Disabling the means of producing radiation’ means ensuring either that the source rack cannot be raised from the fully shielded position or, for an accelerator based system, that the high voltage is disabled.

and motion sensors. Detection of entry by personnel while the source rack is exposed or while the electron beam is energized should disable the means of producing radiation and should actuate visible and audible alarms to make the individual entering the room aware of the hazard.

Safety interlocks for product entry and exit ports

8.15. Suitable means should be provided at the product entry and exit ports to prevent inadvertent entry of personnel into high radiation areas. Methods for accomplishing this include the use of gates or doors that open only to allow product to pass through and then close immediately, and the use of detectors that require that a product carrier always be present in the opening and that cause a safety interlock violation if none is present. The ports should be interlocked so that a visible or audible alarm indicates when the control mechanism for the entry or exit port has malfunctioned or has been overridden or tampered with. It should be arranged that any violation of the safety interlock system disables the means of producing radiation.

Backup access control — Product entry and exit ports

8.16. In addition to the safety interlocks for the product entry and exit ports, each product entry and exit port should have an independent backup control to detect entry of personnel either while the radioactive sources are unshielded or while the electron accelerator is energized. Examples include pressure mats, light beam interruption detectors (photo eyes), infrared detectors and other means of detecting the presence of a person. Detection of the entry of personnel when radiation levels are high should disable the means of producing radiation and actuate visible and audible alarms.

Removable radiation room shield plugs

8.17. Removable radiation room shield plugs should be interlocked with the control system to disable the means of producing radiation if a plug is removed. To prevent tampering, the safety interlock should not be accessible from outside the radiation shield.

Fixed radiation monitor with alarms

8.18. A monitoring system should be provided to monitor the ambient radiation level in the radiation room. The radiation monitor should be used to provide independent verification when the means of producing radiation has been disabled. The monitor should be integrated with the safety interlocks of the personnel access door to prevent access to the radiation room when the monitor detects radiation above a preset level, malfunctions or is switched off. The preset alarm level should be as low as practicable, but high enough to avoid false alarms. The radiation monitor should be designed so that the reading or output does not go to zero under conditions of detector saturation. Before the personnel access door is opened, the irradiator operator should verify that the radiation monitor is operating and that its reading corresponds to background levels of radiation.

8.19. The monitor should actuate visible and audible alarms if the radiation level exceeds the preset level.

Control console

Access key

8.20. Irradiator controls should be designed so that a single multipurpose key can be used to operate the irradiator in normal use. This key should be used both to operate the control console and to gain access to the radiation room, and it may also be the key used to actuate the safety delay timer.

8.21. The multipurpose key should be attached to a portable radiation survey meter by a chain or cable that is long enough to allow easy operation of all key switches. Only one multipurpose key should be available to all authorized personnel.

8.22. In systems in which two or more keys are used, one key should remain captive (i.e. held in the lock) when the other keys are being used.

Emergency stop device at the control console

8.23. In addition to any other means normally available at the control console to shut down the irradiator, a clearly labelled emergency stop device should be provided at the control console for preventing, quickly interrupting or aborting irradiator operations and disabling the means of producing radiation.

Disabling the radiation source

8.24. For the purpose of servicing the irradiator, a method should be provided for disabling the means of producing radiation so that the radiation source cannot be started while servicing operations are being carried out (e.g. by means of a source rack hoist lockout or a high voltage lockout for an accelerator).

Radiation room

Safety delay timer with alarms

8.25. The irradiator should be equipped with a safety delay timer inside the radiation room that is actuated to begin the irradiator startup sequence. The timer should be placed in a location such that, to actuate the timer, the irradiator operator needs to pass through all areas of the radiation room where a person might be present. This encourages the irradiator operator to check the entire radiation room visually prior to starting the radiation source.

8.26. The safety timer will automatically actuate visible and audible warning signals and alarms to alert any personnel who may be in the radiation room that the irradiator startup sequence has begun. The alarms should provide personnel sufficient time to leave the area or to operate a clearly identified emergency stop device that will abort the startup sequence.

8.27. The safety timer should be integrated with the control system so that operation of the radiation source cannot be initiated unless the startup sequence has been completed within the preset time and the control console indicates that it is safe to start the irradiator.

Emergency stop device

8.28. An emergency stop device should be provided within the radiation room for promptly aborting irradiator operations and disabling the means of producing radiation at any time. The emergency stop device should be clearly labelled and should be readily accessible to personnel in the radiation room. It should cause a visible or audible alarm to be generated outside the radiation room.

Emergency exit

8.29. For the safety of anyone inadvertently shut inside the radiation room, a means should be provided to ensure that personnel can leave the radiation room at any time. The individual should first actuate the emergency stop device and then leave the radiation room. Alternatively, the individual should leave the radiation room through the emergency exit, which should actuate visible and audible alarms and should disable the means of producing radiation. In case the emergency stop device does not actuate before the person leaves the radiation room, the most direct exit route that avoids the area near the radiation source should be taken.

Considerations with regard to external events

8.30. External natural events such as events relating to geological and extreme meteorological phenomena and human induced events that could adversely affect the integrity of radiation shielding should be evaluated in accordance with specific characteristics of the irradiation facility and the local site.

8.31. Conventional norms, codes or standards that address hazards due to external events may be used for assessing the potential hazards, and for designing facilities that can withstand such hazards, the radiation risks associated with the facility being taken into account.

8.32. In seismic areas, all irradiation facilities should be equipped with instrumentation to warn of the occurrence of a seismic event and to disable the means of producing radiation. The seismic instrumentation should be firmly anchored to a concrete shield wall. The instrumentation may be of a horizontal, omni-axial type or a vertical, uni-axial type. It should be set to actuate at the lowest practicable level that will not generate false alarms.

8.33. During the process of site selection and evaluation, particular consideration should be given to potential hazards that cannot be addressed by means of engineering measures, such as hazards relating to flooding and hazards relating to geological phenomena in areas of potential or actual subsidence, uplift, collapse or faulting.

Ventilation

8.34. Radiolysis of air produces ozone (O_3), which is unstable and in time reverts to oxygen (O_2). The operating organization of an irradiation facility should assess the levels of ozone produced by the irradiator and should protect personnel against exposure to ozone in concentrations above the limits established by the competent health authority.

8.35. Personnel should be prevented from entering any area where concentrations of ozone may be high. Irradiation facilities should be designed so that ozone will not migrate to occupied areas.

8.36. The following control measures for ozone should be used:

— A ventilation system to exhaust ozone and to maintain a low pressure differential in the irradiator, to prevent the migration of ozone to occupied areas;
— A safety interlock with entry delay to allow for reduction in ozone levels by reversion to diatomic oxygen or removal of ozone by the ventilation system.

8.37. The irradiator control system should be designed to monitor the ventilation system to ensure that it is operating. If the ventilation system fails, either the source rack should be returned to the fully shielded position or the electron beam should be switched off. Entry to the radiation room should not be permitted until ozone levels have fallen.

Notices and symbols

8.38. The radiation symbol (trefoil) [27] and other notices should be placed at entrances to the radiation room and in proximity to the radiation generator or the radioactive source, in accordance with regulatory requirements (Fig. 6). Any

FIG. 6. Basic ionizing radiation symbol (trefoil) (ISO standard 361).

FIG. 7. Ionizing radiation supplementary symbol (ISO standard 21482).

notices and symbols placed inside the radiation room should be made from materials that will resist damage due to high radiation levels and that are durable under the ambient conditions.

8.39. In addition to the radiation symbol (trefoil), the ionizing radiation supplementary warning symbol [28] should also be used on Category II, III and IV gamma irradiators (Fig. 7). This supplementary symbol is intended to inform members of the public that the radioactive source poses a significant danger to them and that they should move away from it. The supplementary symbol should be placed in close proximity to the source; since radioactive sources are small in size, it is normally not practicable to put the supplementary symbol on individual sources.

8.40. In general, the supplementary symbol should not be placed so that it is visible when the radioactive source is in normal use or in storage. Examples of locations on gamma irradiators where the supplementary symbol should be placed are as follows:

— Category II: On the source holder where it may be seen after the cover has been removed;
— Category III: On the structure that holds the source array in place;
— Category IV: On the source rack.

8.41. In general, the addition of the supplementary symbol cannot be justified for operating gamma irradiators if the removal of the radioactive sources would be necessary. Ideally, the symbol should be installed during the construction of the irradiator. The symbol should be installed in an operating irradiator only by an individual who is qualified by training and experience, and who is authorized by the regulatory body to perform servicing and maintenance activities on irradiators.

Irradiation (source) status indicators

8.42. Irradiation status indicators should be provided to show:

— When the irradiation has been terminated (source ‘down’ or beam de-energized).
— When the irradiation is in progress (source ‘up’ or beam energized).
— When either the radioactive source is in transit or the X ray or electron beam is about to be energized. (An audible signal should also be used to indicate this condition.)

8.43. An irradiation status indicator should be clearly visible at the control console and at each access door for personnel and product entry and exit port.

Irradiation status indicator colours

8.44. When illuminated or colour coded controls are used, the following colours should be considered for indicating the specified conditions:

Condition	*Colour*
Emergency (stop buttons or warning lights)	Red
Warning or hazard	International trefoil or red
Critical information (irradiator malfunction)	Red
Caution (not an emergency but heightened awareness is called for)	Yellow or orange
Normal (irradiator is not in use or is functioning safely)	Green
Information	Blue

Audible signals

8.45. Each audible signal used in the irradiator control system should be distinct and loud enough to immediately gain the attention of persons in the area. It should not be capable of being confused with any other signals in use in the area. An audible signal should be used to indicate when either a radioactive source is in transit or the X ray or electron beam is about to be energized.

Labelling and posting

8.46. Indicators and visual signals used to alert individuals should be clearly labelled as to the conditions that prompt actuation of the indicator. Visual warning signals and alarms, such as flashing lights or messages on the control console, should provide the irradiator operator with unambiguous information that is adequate to determine the cause of the warning signal or the alarm so that the appropriate corrective actions can be initiated.

8.47. In addition to notices and symbols, certain information relevant to the operation of the irradiation facility should be posted in clearly visible locations within the facility. This information should include:

- A copy of the licence, registration or other document from the regulatory body authorizing operation of the irradiator. If it is not practicable to post a copy of the authorization, a notice should be posted informing persons of where a copy of the document is available within the facility.
- Emergency contact information, including the names and telephone numbers (or other means of immediate contact) of individuals to be contacted in an emergency.

GAMMA IRRADIATORS

Design of sealed sources

8.48. Radioactive sources used in gamma irradiation facilities meet the design requirements of the BSS [2] when they satisfy the performance and safety testing standards for this practice, for which methods are specified in ISO standards [29, 30]. ISO Standard 2919 [29] establishes a classification system for sealed radioactive sources on the basis of test performance and specifies general requirements, performance tests, production tests, markings and certification.

8.49. The performance tests that apply to radioactive sources used in gamma irradiation facilities vary in severity with the shape of the sources (for bending tests) and the environmental conditions to which the sources are expected to be subjected. The environmental tests for sources used in Category II, III and IV irradiators have been given the classification number 53424, with each digit relating to the severity of the following environmental test conditions, respectively: temperature, external pressure, impact, vibration and puncture.

8.50. This classification does not consider the effects of various other factors including fire, explosion and corrosion, or the possible consequences of events and effects under the conditions in which radioactive sources will be used. ISO Standard 2919 specifies that the manufacturer and user will take into account the probability of fire, explosion and corrosion, and the possible consequences of events and effects if the activity of the sealed sources exceeds the values shown in table 3 of Ref. [29]. Factors that should be considered in determining the need for special testing are:

- Consequences of leakage or dispersion of radioactive material;
- Quantity of radioactive material contained in the sealed source;
- Radiotoxicity;
- Chemical and physical form of the radioactive material;
- Environment in which the sealed source is stored, moved and used;
- Protection afforded to the sealed source or to the source–device combination.

Specific requirements for wet storage conditions

8.51. The outer capsule material of a sealed source should be such that it does not corrode under the conditions of storage of the sealed source in the storage pool. Account should be taken in the selection of the capsule material of the need to withstand thermal fatigue.

8.52. The radioactive material should be substantially insoluble in water so that the possible consequences of a breach in the capsule are mitigated. Caesium chloride should not be used in wet source storage gamma irradiators. Caesium chloride is highly soluble in water, and thermal cycling such as would be encountered in a Category IV irradiator tends to increase the probability of failure of the sealed source encapsulation.

Certification and documentation

8.53. The manufacturer or supplier and users of sealed sources should maintain records relating to the sealed source. The regulatory body may require this information for such purposes as licensing the facility and transporting the radioactive source. The records should include the following:

— Model number, serial number and identification number of the radioactive source, the radionuclide contained, the source activity and the date to which the stated source activity relates;
— ISO Standard 2919 source certificate [29];
— Bend test certificate (if required);
— Leak test certificate;
— Contamination test certificate;
— Special form radioactive material approval certificate, if available (see Ref. [31]);
— Any other documentation as required by the regulatory body.

Internal design

8.54. All equipment inside the radiation room of an irradiation facility, including wiring, electrical equipment, notices and lighting, should be selected so as to minimize failure due to prolonged exposure to radiation.

Source holder and source rack

8.55. The typical gamma irradiator design consists of radioactive sources that are placed in a source holder, referred to as a module, several of which are placed in an array in a source rack. This arrangement is depicted in Fig. 8. The source rack should be designed so that there are no crevices in the source holder, or between the radioactive source and the source holder, that would promote corrosion.

8.56. The sealed source should be firmly fixed within its source holder and source rack so that it cannot be readily dislodged from them. Means should be provided for placing and retaining the sealed source in the design position. Devices used

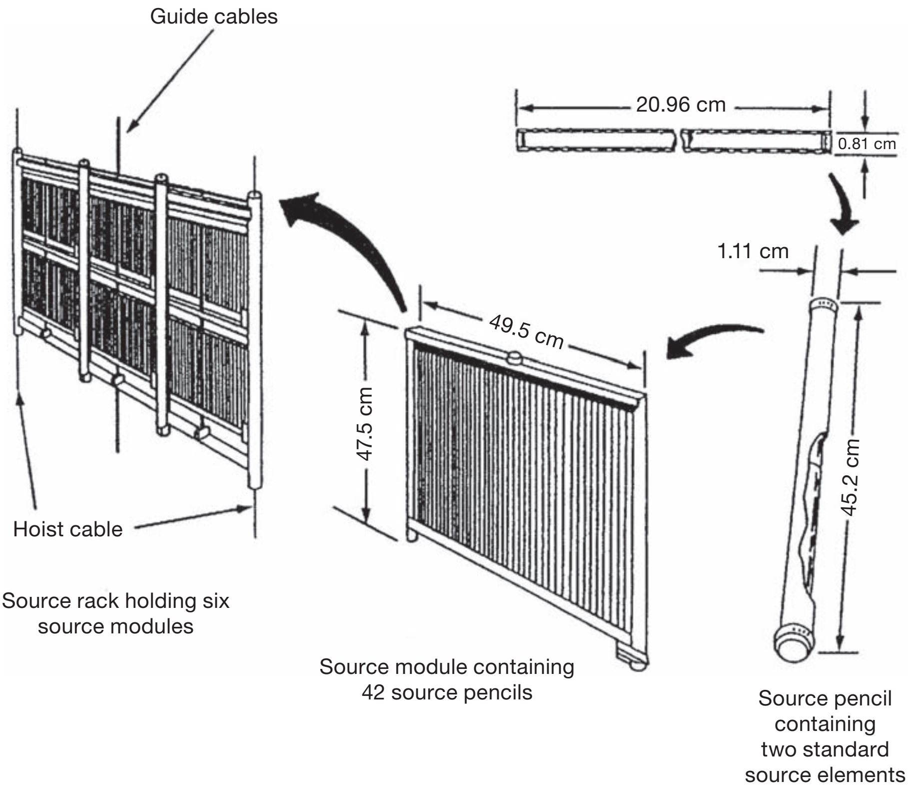

FIG. 8. Typical gamma irradiator source rack and components: Source rack with six source modules, each containing up to 42 source pencils (courtesy of MDS Nordion).

for the purpose of positioning and removing radioactive sources (e.g. tools for manipulating sources from above the water surface of the storage pool) should be capable of being safely operated from outside the radiation shields[17].

8.57. In the event of failure of the source module or source rack, it should not be possible for the sources to move into a position that may cause a radiation hazard. In the event of power failure, the sources and source rack should be able to return to the fully shielded position without damage to either. Failure of hoist cables (or of alternative means of support) should not result in the source rack's moving in such a way that damage is caused to the sealed sources. If the source rack sticks

[17] Radiation shields are structures that have as their primary function the attenuation of radiation emitted by the radiation source to acceptable levels.

in the exposed position, there should be a means of freeing it with minimal risk to personnel (e.g. by using an emergency access port; see para. 8.62).

Source guard

8.58. The source rack should be provided with a source guard for adequate mechanical protection against interference and damage by items such as product boxes or carriers. The source guard may take the form of a protective shroud, guide bars or floor guides on the product positioning mechanism, for example. Product positioning mechanisms should be designed to prevent product from coming into contact either directly or indirectly with the source rack.

8.59. Irradiators should employ a mechanical device for preventing product collisions; this device should be located at the ends of the source rack to sense products or product carriers that are improperly positioned as they enter the source pass[18] closest to the source rack and that could potentially collide with the sources. When actuated, this device should stop the product carrier, return the source rack to the fully shielded position and generate a fault signal on the control console.

Emergency source cooling system

8.60. Some Category IV irradiators use an emergency source cooling system consisting of a water spray head located at the top of the source pass above the source racks. Water from the source storage pool can be diverted to the water spray head via valves outside the shielding. If the source rack were to stick in an unshielded position, generating heat that could cause the product to ignite, pool water would be sprayed onto the source rack to lower the temperature to ensure source integrity.

Source travel timer

8.61. A source travel timer should be connected to the ‘source up’ and ‘source down’ switches to ensure that the source travel time (when moving either up or down) is not in excess of a preset level. If the preset level is exceeded, the control system should indicate a fault, shut down the irradiator, and actuate visible and

[18] The source pass is the component of the product positioning system that carries the product past the source rack.

audible alarms. This safety interlock could give an early warning of a problem with the source rack hoist mechanism for which an inspection is necessary.

Emergency access ports

8.62. Emergency access ports allow access to the radiation room through the shield if there is a malfunction that leaves the radioactive source in an exposed position. Emergency access ports should be used only by authorized personnel for emergency action and recovery.

Source rack position indicators

8.63. The switches of the source rack position ('up' or 'down') indicators should be hardwired directly to the control system and not through a programmable logic controller. Defence in depth can be achieved by ensuring that indicator switches are installed at different locations, such as on the source rack hoist mechanism and on the source rack itself. Supplementary means of confirming the position of the source rack, such as by means of a radiation detector or a camera at the bottom of the storage pool, may be considered in addition to the indicator switches.

8.64. If the indicator switches malfunction or do not respond to the presence of the source rack, whether in the 'down' (fully shielded) or in the 'up' position, with account taken of source rack transit times, visible and audible alarms should be actuated to alert personnel in the area and to prevent access to the radiation room.

Access to radioactive sources and safety interlock systems

Access to storage pools in Category III (self-contained wet source storage) irradiators

8.65. Self-contained wet source storage irradiators (Category III irradiators) should have a personnel access barrier around the source storage pool that is locked to prevent access when the irradiator is unattended. Only irradiator operators and facility managers should have access to keys to the personnel access barrier. An intrusion alarm should be installed to detect entry when the personnel access barrier is locked.

Backup access control — Product entry and exit ports

8.66. In addition to the safety interlocks for the product entry and exit ports (see para. 8.15), each product entry and exit port at a panoramic irradiator should have an independent backup control to detect the entry of personnel while the radioactive source rack is exposed. Examples include pressure mats, light beam interruption devices (photo eyes), infrared detectors or other means of detecting the presence of a person. Detection of entry by personnel while the source rack is in the exposed position should cause the source rack to return to the fully shielded position and should actuate visible and audible alarms to warn the individual entering the room of the hazard.

Removable radiation room shield plugs at gamma irradiators

8.67. Roof plugs designed for access for the purpose of moving transport packages of radioactive material to the source storage pool should be located such that a shipping package, if dropped, will not fall on the source rack.

Fixed radiation monitor with alarms at Category III (self-contained wet source storage) irradiators

8.68. Underwater irradiators that are not in a shielded radiation room should have a radiation monitor over the source storage pool to detect abnormal radiation levels. The monitor should generate visible and audible alarms at entrances to the access barrier around the source storage pool.

Backup system for lowering the source rack

8.69. A backup system should be provided for lowering the source rack to the fully shielded position in the event of a failure of the source rack hoist mechanism. For mechanical hoist systems, this may be a manual brake release to allow the controlled descent of the source rack to the fully shielded position. In pneumatic hoist systems, there should be a second solenoid valve on the source rack hoist as a backup to the main solenoid valve for the source rack hoist. If the main valve fails to exhaust, the second valve should provide a means of exhausting air from the source rack hoist, thus allowing the source rack to descend into the fully shielded position. Failure of the primary means of lowering the source rack should create a fault condition and should actuate visible and audible alarms.

Product exit radiation monitor

8.70. A fixed radiation monitoring system should be located such that monitors will detect any radioactive material being brought out of the radiation room. These monitors should be interlocked with the irradiator controls so that if radiation levels at the exit port exceed a predetermined level, the product positioning system carrying product from the radiation room to the exit port will stop, the radioactive source will automatically be returned to the fully shielded position, and visible and audible alarms will be actuated.

Wet source storage irradiators

8.71. Water is used as the radiation shielding medium in wet source storage irradiators. An automatic water level control should be provided to maintain the water at a level that provides adequate shielding to enable personnel to be in the room while radioactive sources are in the fully shielded position. All components of the automatic water level control system that are below water level, except for float switches, should be made of a material with a specific gravity of 1.0 g/cm^3 or higher. If hollow tubing is used, it should be fully vented[19] to allow water to flood the tubing so as to eliminate the risk of a beam of high level radiation up the tube.

8.72. The source storage pool should be cleaned as necessary to remove foreign matter that has accumulated at the bottom.

8.73. Any vacuum system used for cleaning the source storage pool should be fitted with an in-line filter. The filter should be continuously checked for the presence of radioactive material during the vacuum cleaning operation. If radioactive material is detected, the vacuuming operation should be terminated. All sediment collected in the filter should meet relevant criteria before its disposal. The vacuum system should be designed to recirculate the storage pool water back into the storage pool after filtering. This will ensure that there is no inadvertent release of storage pool water before it has been ensured that the level of contamination is below the authorized limits established by the regulatory body.

[19] ‘Fully vented’ means having the design feature for hollow tools, tubes or control rods for full venting to allow air to escape at a rate sufficient to allow water to flood the immersed section as it enters the storage water pool.

8.74. All tools used for underwater vacuum cleaning should meet the recommendations for venting provided in para. 8.71.

Radiation monitor of the water treatment system

8.75. A fixed radiation monitor should be located on the water treatment system to detect contamination that may arise if a radioactive source leaks. Examples of methods used to install fixed radiation monitors include affixing a radiation detector to the deionization column or particulate filter, and measuring the activity in water directly by means of a continuous flow sampling system.

8.76. If radiation levels exceed a predetermined value, the fixed radiation monitor should actuate visible and audible alarms. The monitor should be interlocked with the irradiator controls so that the source rack is returned to the fully shielded position and the normal circulation of water is stopped if the alarm is actuated. The alarm level should be set sufficiently above the natural background level of radiation to avoid an excessive number of false alarms.

Storage pool integrity

8.77. The source storage pool should be watertight and should be designed to retain water under all reasonably foreseeable circumstances. The storage pool should be constructed of materials that are metallurgically compatible with each other and with the other components that will be in the storage pool, including the radioactive sources. A stainless steel pool liner that is resistant to corrosion and radiation damage and is easily decontaminated should be used. The storage pool should be designed to support the transport packages used during operations for the loading and unloading of sources without compromising the integrity of the pool.

8.78. There should be no penetration (such as pipes or plugged holes) through the bottom of the storage pool. Any penetration through the pool liner should be no more than 30 cm below the normal water level.

Materials of pool components

8.79. All permanent storage pool components should be made of corrosion resistant materials, since corrosion products may affect the integrity of the sealed sources. Where practicable, stainless steel components (such as brackets or pulleys) should be passivated, in particular after fabrication.

Water level control — Level normal

8.80. Means should be provided to replenish water losses from the storage pool; these losses will be principally due to evaporation. The system should be capable of maintaining the pool water above a level sufficient to maintain adequate radiation shielding. A water level control should cause make-up water to flow into the storage pool through a water treatment system when the level reaches the normal low water level position, and should cause water to stop flowing when the level reaches the normal high water level position.

8.81. A metering device should be installed to record the use of replenishment water, changes in which may be associated with pool leakage (such as by the siphoning of water back through the piping of the water supply).

8.82. The storage pool water should be prevented from migrating into municipal water supplies.

Water level control abnormal — Level low

8.83. Visible and audible signals should be generated if the storage pool water falls to a level that would compromise radiation shielding, typically approximately 30 cm below the normal low water level. The signal should alert personnel to investigate and to take corrective action.

Water level control abnormal — Level high

8.84. Visible and audible signals should be generated if the storage pool water continues to rise above the normal high water level cut-off point. The signal should alert personnel to investigate and to take corrective action to prevent the pool water from overflowing.

Water conditioning

8.85. The storage pool should be equipped with a water conditioning system capable of keeping the water clean and at a level of conductivity not exceeding 1000 μS/m for routine operation and not exceeding 2000 μS/m for temporary excursions not exceeding 90 days. Conductivity measurements serve as an indicator of potentially high halide (e.g. chloride and fluoride) levels, which are known to be corrosive to stainless steel. The conductivity of the storage pool water should be monitored continuously.

8.86. Great care should be exercised to avoid the introduction of contaminants into the pool water system (e.g. deionizer regenerants, cleaning materials, fire extinguishing materials, spilled product). Manufacturers of sealed sources have established recommendations for acceptable levels and testing frequencies for water quality indicators such as conductivity, pH and chloride concentrations.

8.87. All filters and resin beds in water treatment systems should be tested for contamination before the removal, backwashing or regeneration of the system. Fluids resulting from backwashing or regeneration should only be released if the level of contamination is below authorized limits established by the regulatory body.

Cooling of storage pool water

8.88. The radioactive decay process generates significant amounts of heat, which will cause water temperatures in the storage pool to rise. Increased water temperature can result in high humidity levels, which can damage electrical equipment and can lead to greater evaporative losses from the storage pool, potentially compromising radiation shielding. If the activity of sealed sources in the source rack is high enough to cause the water temperatures in the storage pool to rise too high, a means of cooling the water during its circulation should be provided. High water temperatures can also cause deionization resins to degrade more rapidly.

In-pool piping

8.89. Since pipes are used in the source storage pool for the water level and water quality control systems, suitable siphon breakers should be provided to prevent the siphoning of storage pool water down to levels that could compromise radiation shielding, typically levels more than 30 cm below the normal make-up water level. Suction pipes for providing circulation of the pool water should have intakes no lower than 30 cm below the normal make-up water level.

Storage pool guard and cover

8.90. A physical barrier, such as a railing or a metal cover, should be installed to prevent personnel from falling into the source storage pool. This physical barrier should be removable for maintenance or service operations.

Fire protection

8.91. A fire extinguishing system should be provided in the radiation room. The control system for the fire extinguishing system should be located outside the radiation room to allow the system to be actuated without the need for personnel to enter the radiation room.

8.92. Radiation rooms equipped with water sprinkler systems should have a shutoff valve outside the radiation room to prevent flooding into unrestricted areas. The maximum ceiling temperature inside the radiation room and the effects on the sprinkler heads of long term subjection to radiation and to ozone should be taken into consideration in selecting a suitable automatic sprinkler head.

8.93. Devices for sensing heat and smoke equipped with visible and audible alarms should be provided to detect combustion in the radiation room. The radioactive source rack should automatically be returned to the fully shielded position and the product positioning system and ventilation systems should shut down if either the heat sensing device or the smoke sensing device is actuated.

8.94. Chemicals and corrosive substances that could adversely affect the integrity of sealed sources should not be used in fire extinguishing systems.

Power failure

Electrical power

8.95. If an electrical power failure of longer than ten seconds occurs[20], the radioactive source rack should automatically be returned to the fully shielded position.

8.96. Critical electronic components used in the irradiator control system should be connected to an uninterruptible power supply capable of providing the necessary electrical power for a controlled shutdown of the irradiator. The radiation room monitor, safety interlocks for access control and source rack

[20] In some areas, short term power failures of not more than ten seconds occur frequently. In such cases, it could be detrimental to some products if automatic irradiator shutdown were to be actuated as a result of the short term power failures. It is acceptable for means to be provided for preventing unnecessary and avoidable shutdowns of the irradiator under conditions of short term power failure.

position indicators should also be powered by the uninterruptible power supply to ensure safe system shutdown.

Non-electrical power

8.97. Failure of non-electrical power (e.g. pneumatic power or hydraulic power) used to control or to operate any safety feature of the irradiator should cause the radioactive source rack to be automatically returned to the fully shielded position.

ELECTRON BEAM IRRADIATORS AND X RAY IRRADIATORS

Safety considerations in the design of electron accelerators

8.98. It is an objective of manufacturers of industrial accelerators to design electron beam irradiation facilities for simplicity and reliability of operation. In pursuit of this end, the designer should be mindful of the possibility of a radiation accident with severe consequences. Inadvertent exposure may result from the investigation of equipment failure or from the maintenance of operating accelerator subsystems while the accelerating stages are improperly or only partially disabled. Also, as long as the capability for electron acceleration remains, there is the possibility of X ray generation by dark current (see footnote 15).

8.99. The possibility of activation of accelerator equipment and ancillary process equipment (such as the beam stop and the product positioning system) and shielding should be taken into account in the design of electron beam irradiation facilities using 10 MeV or higher energy electrons. Depending on the energy and power output of the accelerator, radiation levels due to activated materials in such components may be substantial immediately following shutdown of the accelerator.

8.100. Procedures for maintenance and repair of the equipment, in particular for removal and disposal of potentially activated components, should provide for adequate radiation safety for the protection of individuals who could be exposed owing to the radioactive material. While most activation products would be expected to be relatively short lived, the activity soon after shutdown of the accelerator could be significant in terms of both external and internal exposure of personnel if operations such as welding or drilling were to be performed on activated system components.

8.101. While reliability of operation of the accelerator reduces the risk of inadvertent exposure by reducing the need for repair and maintenance, a further reduction of risk can be achieved by designing for ease of troubleshooting. This may also reduce the likelihood of other hazardous occurrences such as electric shock or overexposure to radiofrequency radiation. In this regard, the following features should be considered in the design of an industrial accelerator:

- — Physical or mechanical means of disabling the main acceleration system;
- — Built-in monitoring of machine parameters;
- — Built-in remote machine diagnostics.

8.102. The operating parameters of accelerators (voltage and current) should be interlocked with the product positioning system.

8.103. Commissioning and testing should be carried out up to maximum operating parameters (voltage and current) and with the product handling equipment in operation.

Disabling mechanism for the main acceleration system

8.104. The disabling mechanism for the main acceleration system, which should remove the applied voltage, should inactivate the means of acceleration without causing harm to machine components. The mechanism should disable the acceleration system in a manner that allows as many other subsystems as possible to function for diagnostic purposes. The disabling feature should be clearly identified, and it should be explained by the manufacturer in the documentation accompanying the accelerator.

Built-in monitoring of machine parameters

8.105. Continuous monitoring of operating parameters for the accelerator should be carried out. Monitoring of operating parameters provides the opportunity for event logging of information on failure sequences for use by maintenance engineers and for the purpose of planning repairs.

Built-in remote machine diagnostics

8.106. Strategic electronic test points should be located outside the radiation room to permit irradiator operators and maintenance crews to carry out machine diagnostics on the total system of the accelerator without having to resort to disabling the main acceleration system or bypassing safety interlocks for access control. For some types of accelerator, closed circuit television monitoring should be considered.

Shielding

8.107. For the application of high energy electrons, the electron beam has to be brought out of vacuum in the accelerator into an atmosphere at ambient pressure (in a chamber filled with air or an inert gas) through a thin window that allows the electrons to pass through with as little energy loss as possible.

8.108. Electrons have a finite range in matter that is a function of their initial energy and the density of the absorbing material. The maximum range of electrons is small compared with that of the X rays that are generated as a consequence of the interaction between the electrons and the matter onto which they impinge. In calculations of the shielding requirements for electron accelerator facilities, only the X rays generated should be taken into account.

8.109. There are two types of X ray generated by the interaction of electrons with matter: bremsstrahlung and characteristic X rays. Characteristic X rays should be considered only for electron accelerators up to 300 keV that are shielded with a heavy element such as lead or depleted uranium. In most cases, bremsstrahlung should be considered more important than characteristic X rays when determining radiation shielding requirements.

8.110. Materials containing elements with a low atomic number should be used as far as possible for structures that are subject to irradiation by electron beams, to minimize the generation of X rays. Shielding calculations should be performed under the assumption that all electrons are absorbed by the heaviest element that may be subject to irradiation by the beam. Account should be taken of the composition of structural materials and the product that might be irradiated in the facility. The shielding calculations are generally performed for the maximum energy and the maximum current that the electron accelerator can deliver.

8.111. Attention should be paid to ‘spurious’ X rays, particularly in accelerators operating at high voltage levels with accelerator tubes located outside the radiation room. There are several causes of this spurious radiation:

— Backscattered electrons can possess sufficient energy to stream back through the accelerator tube. This effect is particularly pronounced when high energy electrons impinge on a target material containing elements with a high atomic number, causing X ray generation.

— During conditioning of the electron accelerator and during operation under relatively poor vacuum conditions, there can be a dark current in the accelerator tube which generates X rays.

8.112. Except in the case of accelerators in the lower energy range (up to about 500 keV) and special purpose machines operating at higher energies, standard concrete will be the preferred shielding material, for economic reasons and to minimize the potential for activation. Examples of the calculation of shielding thickness and the layout of the mazes for access by persons and for the transport of product to and from the radiation room are given in Refs [20, 25].

8.113. In the commissioning of an electron beam irradiation facility, special attention has to be paid to ‘hot spots’; that is, small areas of high intensity radiation due to spurious radiation passing through penetrations in the shielding. Radiation passing through the penetrations should be reduced to acceptable levels. This is often accomplished by means of the use of extra shielding such as shielding made of lead or steel shot. The experience of the manufacturer with existing installations of the same or a similar type should be made available.

Safety considerations in the design of X ray irradiation facilities

8.114. For an X ray irradiation facility, the recommendations made previously for electron beam accelerators should be followed, since the X ray system consists of an electron beam irradiation facility coupled with a high atomic number target in which bremsstrahlung is produced. Specifically, the main disabling mechanism for the acceleration system, built-in monitoring of machine parameters and built-in remote machine diagnostics, as described for electron accelerators, also apply for X ray irradiation facilities.

8.115. Since shielding design for electron irradiation facilities is predicated on the probable production of X rays within the system components and the shield, evaluation of the shielding requirements for an X ray irradiation facility is comparable with that for electron irradiation facilities. The exception is that in an X ray irradiation facility electrons are converted to X rays in a known and predictable manner. This makes the assumptions regarding the generation of bremsstrahlung radiation less uncertain than those for electron irradiation facilities. The efficiency of conversion of electrons to X rays, and consequently the intensity of the emerging X ray beam, is higher for a specially designed X ray target than for the secondary process of generation of bremsstrahlung radiation by electrons impinging on process equipment or product positioning equipment, as would occur in an electron beam irradiation facility.

8.116. Consequently, the barrier thickness directly in front of the beam (primary barrier) should be substantially greater for an X ray irradiation facility than for an electron beam irradiation facility. Similarly, scattered X rays will have a higher intensity in an X ray irradiation facility than in an electron beam irradiation facility. Additional shielding should be provided on secondary barriers and on additional scattering pathways along entrance and exit mazes in an X ray irradiation facility.

8.117. For X ray irradiation facilities operating at 5 MeV and above, the generation of neutrons in the X ray target and their propagation should be considered in the shielding calculations. While the neutron fluence rate may not be a significant factor in the activation of the product being irradiated, the neutron source term can have a substantial influence on the final design of the shield and the mazes.

8.118. Owing to potential for activation at higher energies, shields for X ray irradiation facilities, and in particular for the primary barrier, should not be constructed of metal. Concrete, which has a relatively low effective atomic number, is the preferred construction material for such shields.

8.119. The possibility of activation of the X ray target, accelerator equipment and ancillary process equipment (such as the beam stop and the product positioning system) and shielding should be taken into account in the design of X ray irradiation facilities. Depending on the energy and power output of the X ray accelerator, radiation levels due to activated materials in such components may be substantial immediately following shutdown of the accelerator.

8.120. Procedures for maintenance and repair of the equipment, in particular for removal and disposal of potentially activated components, should provide for adequate radiation safety for the protection of individuals who could be exposed owing to the radioactive material. While most activation products would be expected to be relatively short lived, the hazards due to radioactive material present soon after shutdown of the accelerator could be significant in terms of possible external and internal exposure of personnel if operations such as welding or drilling were to be performed on activated system components.

FACILITY MODIFICATIONS

8.121. Any proposed modifications of the irradiation facility may require the approval of the regulatory body. Modifications should be undertaken only by appropriately qualified persons. Modifications should be thoroughly checked to ensure that they have been carried out properly and that the safety of the irradiation facility has not been compromised.

8.122. The operating organization of the irradiation facility should consult a knowledgeable individual such as a qualified expert and should seek the approval of the regulatory body before carrying out any modifications that have the potential to cause a radiation hazard. Some examples of such modifications are:

— Modifications of operating procedures;
— Modifications of the safety control system;
— Major modifications of the irradiator;
— Loading, replenishment, removal or redistribution of radioactive sources, or electron beam reorientation, in any way at variance with what was approved by the regulatory body;
— Changes in key personnel or advisers.

9. TESTING AND MAINTENANCE OF EQUIPMENT

9.1. The BSS [2], in para. IV.16(g) of appendix IV, state that the operating organization should "ensure that adequate maintenance, testing, inspection and servicing be carried out as needed so that sources remain capable of meeting their design requirements for protection and safety throughout their lifetime."

9.2. To ensure the continued safe operation of the irradiation facility, the operating organization should set up a formal programme of maintenance and testing to test all safety functions regularly. The following actions should be performed periodically (or as otherwise specified below):

— Particular attention should be paid to regular testing of components of the safety interlock system for correct operation, in accordance with the instructions of the equipment manufacturer. These tests should be carried out by appropriately qualified persons in the presence of a radiation protection officer.

— Portable radiation survey meters should be calibrated before their first use, after repair and at the intervals specified in regulatory requirements. The pre-use test should include a test of the instrument’s overload performance; that is, the instrument should be tested to verify that it operates correctly up to the maximum foreseeable dose rate.
— Periodic examination should be made of the source rack hoist cable and guide cables (see footnote 12). The cables should be replaced at the intervals recommended by the manufacturer.
— Periodic leak tests of radioactive sources (see footnote 12) should be carried out in the manner and at the frequency recommended by the source supplier and in accordance with regulatory requirements.

WEEKLY TESTS

9.3. The following tests should be carried out weekly:

— *Category II and IV gamma irradiators*. If air filtration is provided for the irradiation room exhaust system, a portable survey meter should be used to check radiation levels at the air filter banks. All readings should be recorded.
— *Category III and IV gamma irradiators*. A portable survey meter should be used to check radiation levels at the deionizer filter and resin beds. All readings should be recorded. If the deionizer resin bed has a continuous monitor to check for contamination of the storage pool water, additional surveys are not necessary.
— *Category III and IV gamma irradiators*. The water deionizer system should be checked for correct operation.
— *Category III and IV gamma irradiators*. The storage pool water cooler should be checked, and it should be ensured that the temperature of the storage pool water is within authorized limits.
— It should be checked that the access control system, the emergency stop device inside the radiation room and the system for the detection of entry by personnel are functioning. This test may be carried out when each component is tested or actuated during the irradiator startup sequence.

MONTHLY TESTS

9.4. The following additional tests should be carried out on a monthly basis:

- Test that the radiation room radiation monitor is functioning properly; the test should be carried out by exposing the monitor probe to a check source until the alarm sounds.
- Check, in accordance with the manufacturer’s instructions, that access to the radiation room is prevented when the radiation room monitor alarm sounds upon exposing the monitor probe to a check source. Check the emergency exit procedure by ensuring that the personnel access door can be opened from the inside and that other means of exit in an emergency are operating properly.
- Test that the product exit radiation monitor is functioning properly; the test should be carried out with the irradiator operating by exposing the monitor probe to a check source until the alarm sounds. The product positioning system should stop, and the means of producing radiation should be disabled.
- *Category III and IV gamma irradiators*. Check that the continuous radiation monitoring device on the circulation system for the storage pool water is functioning correctly.
- Test irradiator shutdown controls during operation where possible. Check the high temperature switch, the source rack position switches, the backup access control and the earthquake detector.
- Test the source rack hoist mechanism, the ventilation system and any similar hardware that contributes to the safe operation of the irradiator, and the product positioning mechanism.
- Check that other main items of equipment associated with the means of producing radiation function properly and show no signs of excessive wear or potential failure.
- Check that all product containers are undamaged and in good condition.
- *Category III and IV irradiators.* Check the water level control switches (normal level and abnormal level) for correct operation.
- Check for correct functioning of the emergency stop device on the control console and at any other locations.
- Check all visual warning signals and alarms for correct operation. Check all control indicator lights to ensure that they illuminate.
- Attempt to operate the irradiator after deliberately violating the approved startup procedure, to ensure that the safety interlocks and sequential controls are functioning correctly.

— Verify that the uninterruptible power supply[21] (see footnote 12) is functioning properly and is capable of providing adequate electrical power to allow safe shutdown of the irradiator.
— Verify that the heat detectors and smoke detectors are operating properly.
— Verify that safety interlocks on removable shield plugs in the radiation room are operating properly.
— *Category III and IV gamma irradiators*. Evaluate the amount of water added to the source storage pool to determine whether the amount of make-up water added is abnormal (too high or too low). If the amount of water added to the storage pool is abnormally high, investigate whether water is leaking from the pool. If the amount of water added to the storage pool is abnormally low, investigate the operation of the supply system for make-up water.
— Verify that posted notices (e.g. emergency call lists) and symbols are still present, legible and clearly visible.
— Test the safety delay timer by actuating the timer, waiting until the time limit has expired and then attempting startup to verify that the system cannot be started.

9.5. If any of the checks indicate a fault or if safety interlocks do not function properly, the irradiator should not be used until repairs have been made. The return of the irradiator to normal operation should be subject to approval by a radiation protection officer.

SEMIANNUAL TESTS

9.6. Semiannually (or at other approved intervals), for gamma irradiators of Categories II and IV, an inspection of the entire length of the cables in the source rack hoist and suspension system should be carried out. Cables showing signs of excessive wear should be replaced. In addition, the source guard should be visually inspected to ensure that its integrity is maintained.

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[21] An uninterruptible power supply is a backup power supply that, in the event of power failure or power fluctuations, allows enough time for an orderly shutdown of the system or for a standby generator(s) to start up.

LEAK TESTING OF RADIOACTIVE SOURCES

9.7. Routine tests should be conducted to detect possible leakage of radioactive material from sealed sources (see footnote 12). In storage pool type irradiators (Categories III and IV), radiation monitors for the storage pool water or the water treatment system can be used as indicators of source leakage, or pool water samples may be collected for analysis. For dry storage irradiators, samples, typically wipe samples, should be collected from locations where contamination from a possible leaking source would be expected to accumulate.

9.8. Leak tests should be conducted at the intervals prescribed by the regulatory body. Typically, for storage pool type irradiators, for which leak testing consists of monitoring radiation levels in the water or the water treatment system, leak tests for sealed sources are performed on a continuous basis. Leak tests should be conducted every six months for dry storage irradiators.

9.9. If the leak tests do not show activity above the prescribed action level, the test results should be documented and retained for future reference. Leak test records should include:

- — Identification of the irradiator;
- — Date of the test;
- — Leak test method;
- — Identification of the measuring instrument by manufacturer, and model and serial number;
- — Date of the most recent calibration of the measuring instrument;
- — Calculation of the activity detected;
- — Evaluation of test results;
- — Name of the person responsible for the test.

9.10. Tests that reveal the presence of contamination at levels higher than the prescribed action level should be considered evidence that the sealed source is leaking. In this case, the irradiator should be immediately withdrawn from operation and appropriate actions should be taken to prevent exposure of personnel and further dispersal of radioactive material. Such actions should include stopping operation of the radiation room ventilation system and stopping circulation of the storage pool water. The operating organization should immediately isolate the area and should notify the regulatory body, the manufacturer of the equipment and the supplier of the radioactive source.

9.11. Removal of a damaged or leaking radioactive source and its transfer to an authorized recipient may require special authorization from the regulatory body. The source should be removed promptly once the decision to remove it has been made. Removal should be performed by, or under the supervision and in the physical presence of, an individual who is qualified and, if required by the regulatory body, specifically authorized to perform such activities. Unauthorized or untrained persons should not attempt to examine or decontaminate the irradiator under any circumstances.

RECORDS

9.12. A logbook or file should be kept in which all tests, maintenance tasks, modifications of and changes to the irradiator are recorded. Every use of the irradiator should also be recorded in a logbook or file.

9.13. The results of all tests described above should be recorded on a formal checklist signed by a radiation protection officer who has witnessed the tests.

9.14. Since the failure of safety systems could cause exposure of personnel, inspectors from the regulatory body should pay particular attention to these records. The records should be kept for the periods of time prescribed by the regulatory body.

FACILITY MAINTENANCE AND MODIFICATION

9.15. Maintenance operations at the facility should be coordinated with the manufacturer of both the irradiator and the radiation source to ensure that appropriate repairs, modifications and system upgrades are instituted at the facility. Lack of coordination of maintenance with the source manufacturer has been cited as a contributory factor to an accident at a gamma irradiator [1].

9.16. Suppliers and manufacturers of radioactive sources may be specifically authorized by the regulatory body to provide specialized expertise and to perform maintenance functions that the operating organization finds impossible to perform or prohibitive in cost. The operating organization should coordinate with the manufacturer to determine the type and extent of services that can and should be offered.

9.17. For accelerator systems, the manufacturer can provide expertise for the tuning of magnets, upgrades to specific equipment components, and/or replacement of or improvements to wave guides. For gamma irradiators, the source supplier can provide equipment and expertise for inspection of source integrity. This may include the use of underwater cameras to inspect sealed sources at the irradiation facility or the destructive testing of source capsules, performed at the manufacturer's hot cell facilities.

9.18. Regular maintenance of all components of an irradiation facility should be performed in accordance with the manufacturer's instructions.

9.19. The operating organization should not be required to notify the regulatory body when performing routine maintenance procedures, including the changing of components that will not give rise to a radiation hazard or compromise the safety of the irradiator, provided that regulatory requirements and conditions are not violated.

9.20. Manufacturers should issue notifications to advise operating organizations and the regulatory body of any previously unforeseen conditions that could cause accidents, or that have given rise to hazards or potential hazards. Notifications should explain the corrective actions to be taken. Operating organizations should ensure that the corrective actions are implemented, unless there are good reasons for not doing so. In the latter case, the agreement of the regulatory body should be sought, and the reasons should be recorded and reported to the manufacturer.

9.21. In certain situations, it may be necessary to bypass or defeat a safety interlock to repair components of irradiator systems. For example, failure of the radiation room radiation monitor should preclude access to the radiation room, because it cannot be independently verified with the control system that the means of producing radiation has been disabled. In such circumstances, it could become necessary to disable part of the safety interlock system to gain access to the radiation room to replace or repair equipment.

9.22. Bypassing or disabling a safety interlock should be done only with the express, written approval of a radiation protection officer. All circumstances necessitating any component of a safety interlock to be bypassed or disabled should be documented with a description of the circumstances and the actions taken, and with the specific approval of a radiation protection officer.

9.23. If it becomes necessary to bypass or disable a safety interlock, independent verification should be obtained either that the radioactive source is in the fully shielded position or that the accelerator is switched off. Verification may be obtained by means such as the interruption of power to the accelerator, determination of the position of the source rack by observation of the source rack hoist or cables, the use of sensors or detectors that monitor the position of the source rack (e.g. underwater limit switches or cameras), or other methods that do not necessitate entry into the radiation room. All these methods should be defined in procedures that are available at the irradiator.

9.24. The affected component of the safety interlock system should be bypassed or disabled only long enough to allow entry into the radiation room to remedy the problem (e.g. to repair or replace the monitor), during which time the irradiator will not be in operation. Entry into the radiation room should be accomplished by following routine procedures, including the use of a portable survey meter to monitor radiation levels on entry.

9.25. If it is necessary to bypass or disable a component of a safety system, the affected component should be tested for proper operation upon being reinstated. The specific test will depend on which component is to be tested, but the test should be the same as the routine test performed to verify proper operation. After verifying that the safety interlocks have been restored to their design function, approval of a radiation protection officer should be obtained for a return to normal operations.

9.26. Since bypassing or disabling any component of the safety interlock system is to be avoided except under abnormal circumstances, routine and preventive maintenance functions should be designed to obviate the necessity to bypass safety interlocks. For example, the radiation room radiation monitors should be periodically replaced to avoid failure during operation. The interval for replacing the detectors will depend on the number of irradiator operating hours and the intensity of the radiation field to which the detectors are subjected.

10. TRANSPORT, LOADING AND UNLOADING OF RADIOACTIVE SOURCES

TRANSPORT

10.1. The BSS [2], in para. 2.9, state that the transport of radioactive sources is subject to the requirements of the IAEA Regulations for the Safe Transport of Radioactive Material [31] and to any applicable international convention. When irradiator sources are transported between States, the relevant portions of the Code of Conduct on the Safety and Security of Radioactive Sources [16] and the supporting Guidance on the Import and Export of Radioactive Sources [18] should be considered.

10.2. Measures should be taken to ensure that radioactive material is kept secure during transport so as to prevent theft or damage and to ensure that control over the material is not relinquished inappropriately. Further recommendations and guidance on the security of radioactive material in transport is given in IAEA Nuclear Security Series No. 9 [32].

LOADING AND UNLOADING OF SOURCES

Handling of radioactive sources

10.3. The unloading and handling of radioactive sources on arrival at the irradiation facility or the loading and handling of sources on dispatch from the facility are potentially hazardous operations and should be undertaken under close supervision for radiation protection purposes. Safety in these operations depends on cooperation between those primarily responsible for radiation protection and those who load or unload the radioactive sources. In many cases the latter will be the source supplier, who may be specifically authorized by the regulatory body to perform this activity. The prime responsibility for safety while radioactive sources are at the irradiation facility resides with the operating organization.

10.4. Source containers, which are normally transport packages, may be introduced into the irradiator by different routes (e.g. through the roof, along the maze, through the wall), depending on the type of irradiator. For wet source storage irradiators, the transport package should be placed at the bottom of the storage pool and should be fully vented. Long handled instruments should be used to manipulate radioactive sources under water. For dry source storage irradiators, remote instruments should be used to manipulate radioactive sources.

10.5. The operating organization should ensure that an assessment is made of any hazards associated with the loading, unloading and handling of radioactive sources. For these activities, the operating organization should ensure the optimization of protection and safety, and should specifically ensure that the safety interlocks and control system of the irradiator are not compromised. Any necessary contingency plans should be incorporated into the written instructions for operation of the facility.

Survey of transport packages

10.6. Radiation surveys of transport packages including radioactive sources should be performed when they are received at irradiation facilities. The following surveys should be performed by appropriately trained individuals.

— *External radiation survey.* Prior to performing the contamination surveys, the operating organization should verify that dose rates due to the transport package do not exceed regulatory requirements. This should be done by means of measurements made at the surface of the package and at one metre from its surface. A survey of the transport vehicle, including occupied areas, should be performed to verify that any shifting of the package that may have occurred during transport has not resulted in high radiation levels in and around the vehicle.
— *External removable contamination survey.* The operating organization should perform a contamination survey of the external surface of the radioactive source transport package, which should consist of a series of wipes to check for the presence of removable contamination.
— *Internal removable contamination survey.* The sealed sources should have been tested for leakage before being placed into the transport package. The operating organization should perform tests to determine whether source integrity has been compromised during transport by checking for the presence of removable contamination inside the transport package. This test, procedures for which will be provided by the supplier of the transport package, consists of passing a fluid (air or water) through the interior cavity of the transport package, filtering particulate from the fluid stream and measuring the filters to detect contamination.

10.7. If exposure rates or contamination levels exceed authorized limits, including those specified in transport documentation, or exceed the limits set by the supplier, actions should be taken to protect workers and members of the public from the hazard. A radiation protection officer should be informed of the situation immediately. The consignor of the shipment should also be notified, and the relevant regulatory bodies should be notified as required by regulations. An investigation into the cause of the elevated dose rates and/or the contamination should be made, and corrective actions should be taken before the source loading procedure is started.

10.8. For returning empty transport packaging following the loading of a source, the same series of surveys should be performed, except that the internal contamination survey should consist of taking wipe samples from inside the packaging cavity, in place of the test described above. If sealed sources are being returned to the manufacturer, the same series of surveys should be performed as described for the receipt of radioactive sources at the facility, except for the internal removable contamination survey.

11. EMERGENCY PREPAREDNESS AND RESPONSE

11.1. The basic obligations, responsibilities and requirements for emergency preparedness and response are established in Ref. [33] and in the BSS [2]. Guidance on preparedness for a nuclear or radiological emergency is provided in IAEA Safety Standards Series No. GS-G-2.1 [34]. Information on developing and maintaining an effective emergency response capability is provided in Ref. [35].

11.2. If a safety assessment concludes that an accident is likely to affect workers or members of the public, it is the responsibility of the operating organization to prepare emergency plans designed to ensure the protection and safety of anyone who may be affected by the accident. A qualified expert may be consulted when drawing up emergency plans.

11.3. Response to an emergency consists of initial actions to be taken immediately and follow-up actions to be taken subsequently. Some follow-up actions may be taken by the manufacturer of the irradiator or the radioactive source rather than by the operating organization, depending on the resources necessary to implement the actions.

11.4. In specifying actions to be taken in response to an emergency, the emergency plan should provide for minimizing radiation exposure, regaining control of the situation to restore the site to its normal conditions, and treating any persons who have been injured or overexposed. In general, apart from potential hazards due to any activation products that may be present, disconnecting the electrical power to an accelerator will reduce or eliminate further radiation hazards at an electron beam irradiator or an X ray irradiator.

The possibility of contamination should be considered in specifying immediate actions that may be taken in response to an emergency involving a gamma irradiator. Immediate actions in response to an emergency involving a gamma irradiator should include the following, depending on the circumstances:

- Evacuating the area in the proximity of the hazard;
- Informing persons in the immediate vicinity of the accident;
- Rendering first aid to any injured persons;
- Notifying a radiation protection officer;
- Evaluating the cause and extent of the hazard;
- Setting up appropriate notices and barriers to secure the area against unauthorized entry, including the construction of temporary shielding in the event that shielding integrity has been compromised, until post-accident recovery operations have been completed.

DEVELOPMENT OF EMERGENCY PLANS

11.5. On the basis of the safety assessment performed for the facility, the operating organization should draw up an emergency plan. Emergency planning should incorporate measures for defence in depth to cope with identified events. The reliability of safety systems (including administrative and operational procedures and design of the facility and equipment) should be evaluated. Operational experience, lessons learned from emergencies at similar facilities [1], and errors made in maintenance and in quality management programmes also serve as sources of information for developing emergency plans.

11.6. In general, the following situations should be considered reasonably foreseeable events:

- For gamma irradiators, electron beam irradiators and X ray irradiators:
  - Malfunction or deliberate defeat of the safety interlock system and access control systems;
  - Fire or explosion inside the radiation room;
  - Jamming of automatic conveyor systems;
  - Natural phenomena, including earthquakes, tornadoes, floods or other phenomena as appropriate for the location of the facility.
- For gamma irradiators only:
  - Radioactive source rack stuck in an unshielded position;
  - Radiation alarm from the product exit port monitor or the radiation monitor for the storage pool water;
  - Detection of leaking radioactive sources or contamination of the source storage pool, or an alarm caused by contamination of pool water;
  - Abnormal (low or high) water level indicator, an abnormal water loss or leakage from the source storage pool;
  - Prolonged loss of electrical power.

11.7. For gamma irradiators, the possibility of an accident during transport of radioactive sources should be considered. Planning for emergency response to transport accidents will probably not be the sole responsibility of the operating organization. The operating organization should liaise with the radioactive source supplier and the carrier to ensure that emergency planning for the transport of radioactive sources to and from the facility is adequately addressed.

11.8. The emergency plan should be specific to each situation and should include, as appropriate:

- Identification of reasonably foreseeable accidents and other incidents or occurrences and their predicted consequences;
- Communication procedures, including an emergency call out list;
- Recommended actions for specified situations, a list of persons able to implement and take responsibility for stated parts of the plan, and specification of situations requiring evacuation together with procedures for implementation;
- A statement regarding immediate life-saving actions;
- Statutory responsibilities and the names of persons able to take actions to discharge them;
- Availability of emergency equipment, including a list of the equipment that should be available and its location;

— Availability of first aid equipment, including a list of the equipment that should be available, its location and the names of persons trained to use it (where applicable);
— An outline of the post-emergency recovery procedures designed to restore normal operating conditions.

11.9. Emergency procedures should consist of concise, unambiguous and easily followed instructions. They should identify situations requiring emergency actions and specify the immediate action to be taken to minimize radiation exposures to persons in the vicinity of the irradiator. They should foresee the development of a written contingency plan for effecting entry into the irradiation room.

11.10. The plan should contain the names and telephone numbers of the responsible individuals to be contacted. Notices should be clearly visibly inside the facility at locations where they might be needed, showing:

— How to contact a radiation protection officer or an alternative person, who should be notified immediately of any emergency;
— How to call the fire brigade and medical services;
— Where to find emergency equipment.

11.11. In an emergency, liaison should be maintained with relevant off-site services or agencies, as appropriate to the situation. These services or agencies will include ambulance, fire, police and hospital services, and local and national authorities. In the event of an accident, it is the duty of the operating organization to initiate the emergency procedures, to coordinate the initial response of the emergency services and other bodies, and to inform the regulatory body and all relevant parties.

11.12. For emergencies in which follow-up action is required to remedy the situation, such as a stuck source rack in a gamma irradiator, the manufacturer or equipment supplier should be contacted, along with the regulatory body. The equipment supplier should have specialized knowledge in dealing with such situations and may be able to offer immediate advice by telephone.

EMERGENCY EQUIPMENT

11.13. Operating organizations should ensure that all necessary equipment is readily available to deal with foreseeable emergencies. For accidents at gamma irradiators, the items listed below should be included. Irradiator facilities with machine produced radiation sources may not require all the radiation detection instruments listed below. The specific equipment required would be determined in the development of the facility emergency plan.

— Appropriate and functioning survey meters to measure both dose rates and contamination;
— Personal alarm and direct reading dosimeters (preferably electronic);
— Additional personal dosimeters (thermoluminescent dosimeters or film badges);
— Barrier materials and notices;
— Communication equipment (e.g. mobile phones, walkie-talkies);
— Spare batteries for survey meters, personal electronic dosimeters, mobile phones and torches;
— Suitable stationery supplies, including an incident logbook;
— Equipment manuals;
— First aid equipment;
— A copy of the emergency procedures.

11.14. Emergency equipment should be kept in a clearly labelled cabinet in a readily accessible place. A list of the emergency equipment should be affixed to the cabinet. Audits should be made periodically and immediately after use of the equipment to ensure that all items are present and functioning correctly, or that they are replaced as necessary.

TRAINING FOR EMERGENCIES

11.15. All persons with a role in the emergency plans should be adequately trained to ensure efficient and effective performance of their roles. This should include both familiarization with and understanding of the emergency plans, together with training in the use of the emergency equipment. Training should be reviewed and recorded at appropriate intervals.

11.16. The operating organization is required to inform staff of any emergency plan that might affect their area of work, and of their role if the plan has to be implemented, and it should arrange for staff training and emergency drills appropriate to each situation. Training should include the review of lessons learned from previous emergencies.

11.17. At intervals commensurate with the potential hazards, emergency exercises should be held to test critical components of the emergency plans. In addition to personnel training, these exercises serve as an evaluation of the adequacy of the emergency plan. Any lessons learned from the conduct of emergency exercises should be reviewed, documented and incorporated into training programmes or emergency plans as appropriate.

PERIODIC REVIEWS OF EMERGENCY PLANS

11.18. The operating organization should review the emergency plan at appropriate intervals, normally not exceeding 12 months. This is to ensure that:

- — Names of persons and contact details (telephone and fax numbers, email addresses, etc.) are up to date;
- — Emergency equipment is readily available and is maintained;
- — Contingency planning is still adequate to address reasonably foreseeable events.

11.19. Emergency plans should always be reviewed following relevant operational changes and in conjunction with analysis of and lessons learned from accidents in similar facilities or with similar radiation sources.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Lessons Learned from Accidents in Industrial Irradiation Facilities, IAEA, Vienna (1996).

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

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary: 2007 Edition, IAEA, Vienna (2007).

[4] EUROPEAN ATOMIC ENERGY COMMUNITY, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Categorization of Radioactive Sources, IAEA Safety Standards Series No. RS-G-1.9, Vienna (2005).

[6] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, Regulatory Control of Radiation Sources, IAEA Safety Standards Series No. GS-G-1.5, IAEA, Vienna (2004).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Notification and Authorization for the Use of Radiation Sources: Supplement to IAEA Safety Standards Series No. GS-G-1.5, IAEA-TECDOC-1525, IAEA, Vienna (2007).

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

[9] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Protection from Potential Exposures: Application to Selected Radiation Sources, ICRP Publication No. 76, ICRP, Oxford, New York and Tokyo (1997).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Radiation Generators and Sealed Radioactive Sources, IAEA Safety Standards Series No. RS-G-1.10, IAEA, Vienna (2006).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Case Studies in the Application of Probabilistic Safety Assessment Techniques to Radiation Sources: Final Report of a Coordinated Research Project, 2001–2003, IAEA-TECDOC-1494, IAEA, Vienna (2006).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Inspection of Radiation Sources and Regulatory Enforcement: Supplement to IAEA Safety Standards Series No. GS-G-1.5, IAEA-TECDOC-1526, IAEA, Vienna (2007).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, Assessment of Occupational Exposure Due to External Sources of Radiation, IAEA Safety Standards Series No. RS-G-1.3, IAEA, Vienna (1999).
[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Workplace Monitoring for Radiation and Contamination, Practical Radiation Technical Manual, IAEA, Vienna (2004).
[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Calibration of Radiation Protection Monitoring Instruments, Safety Reports Series No. 16, IAEA, Vienna (2000).
[16] Code of Conduct on the Safety and Security of Radioactive Sources, IAEA/CODEOC/2004, IAEA, Vienna (2004).
[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Security of Radioactive Sources, IAEA Nuclear Security Series No. 11, IAEA, Vienna (2009).
[18] Guidance on the Import and Export of Radioactive Sources, IAEA/CODEOC/IMP-EXP/2005, IAEA, Vienna (2005).
[19] NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, Radiation Protection for Particle Accelerator Facilities, Report No. 144, NCRP, Washington, DC (2003).
[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiological Safety Aspects of the Operation of Electron Linear Accelerators, Technical Reports Series No. 188, IAEA, Vienna (1979).
[21] BRITISH STANDARDS INSTITUTION, Recommendation for Data on Shielding from Ionizing Radiation, Part 1: 1966, Shielding from Gamma Radiation, BS 4094, BSI, London (1988).
[22] BRITISH STANDARDS INSTITUTION, Recommendation for Data on Shielding from Ionizing Radiation, Part 2: 1971, Shielding from X Radiation, BS 4094, BSI, London (1988).
[23] NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, Structural Shielding Design for Medical X-Ray Imaging Facilities, Report No. 147, NCRP, Washington, DC (2004).
[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection in the Design of Radiotherapy Facilities, Safety Reports Series No. 47, IAEA, Vienna (2006).
[25] NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, Structural Shielding Design and Evaluation for Megavoltage X- and Gamma-Ray Radiotherapy Facilities, Report No. 151, NCRP, Washington, DC (2005).
[26] PORTLAND CEMENT ASSOCIATION, Concrete Information Article, “Effect of long exposure of concrete to high temperature”, ST32-3-53, Skokie, Illinois, USA (1969).
[27] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Basic Ionizing Radiation Symbol, ISO 361:1975, ISO, Geneva (1975).
[28] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Ionizing-Radiation Warning — Supplementary Symbol, ISO 21482, ISO, Geneva (2007).
[29] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Radiation Protection — Sealed Radioactive Sources — General Requirements and Classification (ISO 2919:1999(E)), ISO, Geneva (1999).
[30] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Radiation Protection — Sealed Radioactive Sources — Leakage Test Methods, ISO 9978:1992(E), ISO, Geneva (1992).

[31] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulations for the Safe Transport of Radioactive Material, 2009 Edition, IAEA Safety Standards Series No. TS-R-1, IAEA, Vienna (2009).
[32] INTERNATIONAL ATOMIC ENERGY AGENCY, Security in the Transport of Radioactive Material, IAEA Nuclear Security Series No. 9, IAEA, Vienna (2008).
[33] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS OFFICE FOR THE CO-ORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GS-R-2, IAEA, Vienna (2002).
[34] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, Arrangements for Preparedness for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GS-G-2.1, IAEA, Vienna (2007).
[35] INTERNATIONAL ATOMIC ENERGY AGENCY, Method for Developing Arrangements for Response to a Nuclear or Radiological Emergency, EPR-METHOD (2003), IAEA, Vienna (2003).

CONTRIBUTORS TO DRAFTING AND REVIEW

MacKenzie, C	International Atomic Energy Agency
McKinnon, D.	Consultant, Canada
Plante, J.	Canadian Nuclear Safety Commission, Canada
Reber, E.	International Atomic Energy Agency
Smith, M.	Sterigenics International, United States of America
Tattersall, P.	Health Protection Agency, United Kingdom

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