IAEA Safety Standards
for protecting people and the environment

Radiation Safety in the Use of Nuclear Gauges

Specific Safety Guide
No. SSG-58

IAEA
International Atomic Energy Agency

IAEA SAFETY STANDARDS AND 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.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available on the IAEA Internet site

https://www.iaea.org/resources/safety-standards

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: Vienna International Centre, PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

RELATED PUBLICATIONS

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

Reports on safety in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Emergency Preparedness and Response** publications, **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

RADIATION SAFETY IN THE USE OF NUCLEAR GAUGES

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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-58

RADIATION SAFETY IN THE USE OF NUCLEAR GAUGES

SPECIFIC SAFETY GUIDE

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FOREWORD

The IAEA's Statute authorizes the Agency to "establish or adopt… standards of safety for protection of health and minimization of danger to life and property" — standards that the IAEA must use in its own operations, and which States can apply by means of their regulatory provisions for nuclear and radiation safety. The IAEA does this in consultation with the competent organs of the United Nations and with the specialized agencies concerned. A comprehensive set of high quality standards under regular review is a key element of a stable and sustainable global safety regime, as is the IAEA's assistance in their application.

The IAEA commenced its safety standards programme in 1958. The emphasis placed on quality, fitness for purpose and continuous improvement has led to the widespread use of the IAEA standards throughout the world. The Safety Standards Series now includes unified Fundamental Safety Principles, which represent an international consensus on what must constitute a high level of protection and safety. With the strong support of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its standards.

Standards are only effective if they are properly applied in practice. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

Regulating safety is a national responsibility, and many States have decided to adopt the IAEA's standards for use in their national regulations. For 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 regulatory bodies and operators around the world to enhance safety in nuclear power generation and in nuclear applications in medicine, industry, agriculture and research.

Safety is not an end in itself but a prerequisite for the purpose of the protection of people in all States and of the environment — now and in the future. The risks associated with ionizing radiation must be assessed and controlled without unduly limiting the contribution of nuclear energy to equitable and sustainable development. Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them.

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. Requirements, including numbered 'overarching' requirements, are expressed as 'shall' statements. 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

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

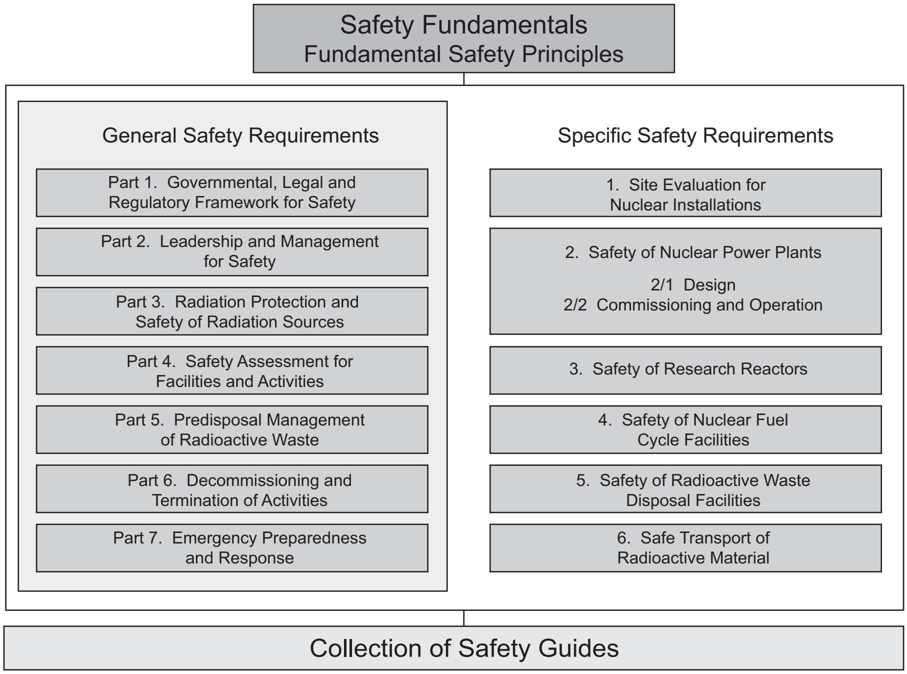

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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 five safety standards committees, for emergency preparedness and response (EPReSC) (as of 2016), 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).

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.

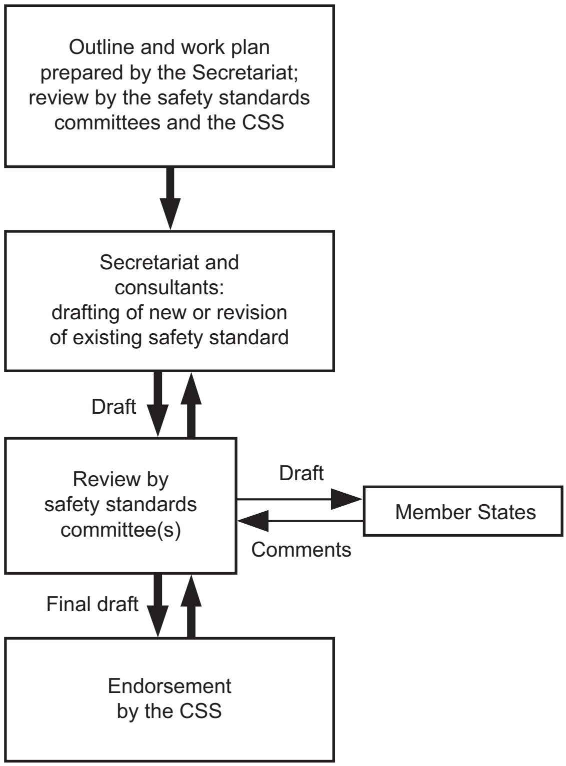

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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. As stated in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [1]: "**The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation.**" Paragraph 2.1 of SF-1 [1] states:

> "This fundamental safety objective of protecting people — individually and collectively — and the environment has to be achieved without unduly limiting the operation of facilities or the conduct of activities that give rise to radiation risks."

1.2. Paragraph 2.2 of SF-1 [1] states:

> "The fundamental safety objective applies for all facilities and activities, and for all stages over the lifetime of a facility or radiation source, including planning, siting, design, manufacturing, construction, commissioning and operation, as well as decommissioning and closure. This includes the associated transport of radioactive material and management of radioactive waste."

1.3. There are several hundred thousand nuclear gauges incorporating a radioactive source or a radiation generator in use all over the world. They have been used in a wide range of industries [2] to improve the quality of products, optimize processes, and save energy and materials. The economic benefits have been amply demonstrated and there is clear evidence that nuclear gauge technology can be used safely and will continue to play an important role in a wide range of industries.

1.4. There are three main categories of nuclear gauge used in industry [2]:

(a) Transmission gauges, used to measure density, thickness and levels of materials: The source housing and the radiation detector are on opposite sides of the material under investigation and the radiation is attenuated as it travels through the material. Such gauges traditionally used radioactive sources (beta and gamma); however, X ray generators are increasingly being used and are now a popular type of radiation source in transmission gauges.

(b) Backscatter gauges, used to measure the thickness of coatings: The detector and source housing are on the same side of the material and therefore the detector has to be shielded from the primary radiation. The radiation enters the material, interacts with it and scatters back. Radioactive sources (beta, gamma and occasionally neutron) are typically used in such gauges. The back-scattered radiation is measured by the radiation detector and is related to the coating thickness.
(c) Reactive gauges, for example used for elemental analysis: Certain radiation sources (X ray and neutron) can cause fluorescent X ray emissions in the material being analysed. X ray generators and neutron sources (radioactive sources or radiation generators) are used in some reactive gauges.

Annex I presents an overview of the main radiation sources used in nuclear gauges for different applications.

1.5. IAEA Safety Standards Series No. RS-G-1.9, Categorization of Radioactive Sources [3] provides a relative ranking of radioactive sources in terms of their potential to cause severe deterministic effects (i.e. how potentially hazardous they could be if misused). The categorization system set out in RS-G-1.9 has five categories, wherein sources in Category 1 are considered to be the most ‘dangerous’. Radioactive sources used in nuclear gauges normally fall into Category 3 or Category 4.

1.6. This Safety Guide is one of a number of Safety Guides on industrial uses of ionizing radiation, including for industrial irradiators, industrial radiography, well logging and radioisotope production facilities [4–7].

1.7. Unless otherwise stated, terms used in this Safety Guide have the meanings ascribed to them in the IAEA Safety Glossary [8].

1.8. It is assumed in this Safety Guide that an effective governmental, legal and regulatory infrastructure for radiation safety for the use of nuclear gauges is in place in the State.

OBJECTIVE

1.9. The objective of this Safety Guide is to provide recommendations on how to meet the relevant requirements of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [9] in relation to the use of nuclear gauges.

1.10. The guidance in this publication is aimed primarily at operating organizations that are authorized to use nuclear gauges, as well as their employees and radiation protection officers. The guidance will also be of interest to regulatory bodies, and to designers, manufacturers, suppliers, and maintenance and servicing organizations of nuclear gauges.

SCOPE

1.11. This Safety Guide provides recommendations on the design, construction and use of fixed (i.e. installed) nuclear gauges and portable (mobile) nuclear gauges. This Safety Guide specifically considers: the responsibilities of relevant parties; the installation, use, maintenance and decommissioning of nuclear gauges; developing safety assessments and local rules; radiation monitoring; transport of radioactive material; and arrangements for preparedness and response for incidents and accidents.

1.12. This Safety Guide also provides information on the need for appropriate nuclear security measures and provides recommendations on their interfaces with safety measures, but does not provide specific guidance on aspects of nuclear security. Additional guidance on nuclear security can be found in the IAEA Nuclear Security Series.

1.13. The use of radiation sources for security purposes (e.g. X ray inspection of luggage for dangerous items) is outside the scope of this Safety Guide.

STRUCTURE

1.14. Section 2 describes the duties and responsibilities of organizations and individuals in respect of nuclear gauges. The preparation of a safety assessment and a radiation protection programme for nuclear gauges are described in Sections 3 and 4, respectively. Recommendations on training of personnel are provided in Section 5. Sections 6 and 7 provide recommendations on individual monitoring of workers and workplace monitoring, respectively. Subsequent sections provide recommendations on the control of radioactive sources (Section 8), the security of radioactive sources (Section 9), the safe use of fixed nuclear gauges and portable nuclear gauges (Sections 10 and 11, respectively), and the safe transport of radioactive sources (Section 12). Preparedness for and response to emergencies involving gauging sources is described in Section 13.

1.15. An overview of nuclear gauge radiation sources and applications is provided in Annex I. Considerations for a safety assessment for nuclear gauges and for local rules for nuclear gauges are provided in Annex II. Some examples of incidents involving nuclear gauges are given in Annex III.

2. DUTIES AND RESPONSIBILITIES

GENERAL

2.1. IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [10] establishes requirements for the governmental, legal and regulatory infrastructure for safety of facilities and activities, including those associated with the use of nuclear gauges, and assigns duties and responsibilities to relevant parties. GSR Part 3 [9] provides the general framework for these duties and responsibilities, and this section provides recommendations on the various duties and responsibilities in the context of nuclear gauges.

THE GOVERNMENT AND THE REGULATORY BODY

2.2. Paragraph 2.15 of GSR Part 3 [9] states:

> "The government shall establish legislation that, among other things:
>
> (a) Provides the statutory basis for requirements for protection and safety for all exposure situations;
> (b) Specifies that the prime responsibility for protection and safety rests with the person or organization responsible for facilities and activities that give rise to radiation risks;
> (c) Specifies the scope of its applicability;
> (d) Establishes and provides for maintaining an independent regulatory body with clearly specified functions and responsibilities for the regulation of protection and safety;
> (e) Provides for coordination between authorities with responsibilities relevant to protection and safety for all exposure situations."

A sound legal and governmental infrastructure, including a national regulatory body with well defined responsibilities and functions, is vital for the achievement and maintenance of a high level of safety in the use of radiation sources in nuclear gauges.

2.3. Paragraph 2.16 of GSR Part 3 [9] states:

> "The government shall ensure that the regulatory body is effectively independent, in making decisions relating to protection and safety, of persons and organizations using or promoting the use of radiation and radioactive material, so that it is free from any undue influence by interested parties and from any conflicts of interest; and shall ensure that it has functional separation from entities having responsibilities or interests that could unduly influence its decision making."

The regulatory body should have no stake in the development and utilization of the technology that it is regulating.

2.4. Paragraph 2.17 of GSR Part 3 [9] states that: "The government shall ensure that the regulatory body has the legal authority, competence and resources necessary to fulfil its statutory functions and responsibilities."

2.5. Requirement 3 of GSR Part 3 [9] states that: "**The regulatory body shall establish or adopt regulations and guides for protection and safety and shall establish a system to ensure their implementation.**" Many States have decided to adopt the IAEA's standards for use in their national regulations.

2.6. Paragraph 2.30 of GSR Part 3 [9] states:

> "The regulatory body shall establish a regulatory system for protection and safety that includes [see Ref. 10]:
>
> (a) Notification and authorization;
> (b) Review and assessment of facilities and activities;
> (c) Inspection of facilities and activities;
> (d) Enforcement of regulatory requirements;
> (e) The regulatory functions relevant to emergency exposure situations and existing exposure situations;
> (f) Provision of information to, and consultation with, parties affected by its decisions and, as appropriate, the public and other interested parties."

2.7. Paragraph 2.31 of GSR Part 3 [9] states:

> "The regulatory body shall adopt a graded approach to the implementation of the system of protection and safety, such that the application of regulatory requirements is commensurate with the radiation risks associated with the exposure situation."

The graded approach should ensure that the application of regulatory resources is optimized while effectively verifying regulatory compliance.

2.8. Paragraph 2.32 of GSR Part 3 [9] states that: "The regulatory body shall ensure the application of the requirements for education, training, qualification and competence in protection and safety of all persons engaged in activities relevant to protection and safety."

2.9. Paragraph 2.33 of GSR Part 3 [9] states:

> "The regulatory body shall ensure that mechanisms are in place for the timely dissemination of information to relevant parties, such as suppliers of and users of sources, on lessons learned for protection and safety from regulatory experience and operating experience, and from incidents and accidents and the related findings. The mechanisms established shall, as appropriate, be used to provide relevant information to other relevant organizations at the national and international level."

In many States, the regulatory body periodically communicates with relevant parties, such as suppliers of and users of sources, through newsletters that provide information on topics such as safe work practices and details of incidents involving radiation sources that have occurred in the State or elsewhere so that lessons learned can be implemented to improve protection and safety.

2.10. Paragraph 2.34 of GSR Part 3 [9] states:

> "The regulatory body, in conjunction with other relevant authorities, shall specify requirements for acceptance and for performance, by regulation or by the application of published standards, for any manufactured or constructed source, device, equipment or facility that, when in use, has implications for protection and safety."

2.11. Radioactive sources used in nuclear gauges should have the relevant characteristics, and meet the performance and safety testing criteria, specified in

ISO 2919 [11]. An example of acceptance and performance criteria for gauges designed for permanent installation is provided in IEC 62598 [12]. The regulatory body should establish or adopt performance standards and specific acceptance criteria for nuclear gauges and associated radiation sources that are authorized for distribution and use.

2.12. Paragraph 2.35 of GSR Part 3 [9] states (footnote omitted):

> "The regulatory body shall make provision for establishing, maintaining and retrieving adequate records relating to facilities and activities. These records shall include:
>
> — Registers of sealed sources and radiation generators;
> — Records of doses from occupational exposure;
> — Records relating to the safety of facilities and activities;
> — Records that might be necessary for the shutdown and decommissioning or closure of facilities;
> — Records of events, including non-routine releases of radioactive material to the environment;
> — Inventories of radioactive waste..."

Records relating to the safety of nuclear gauges should also include inventories of radiation sources in use and of disused sources.

2.13. The regulatory body should also make provision for establishing, maintaining and retrieving adequate records of:

(a) The transport of radioactive sources;
(b) The location of radioactive sources;
(c) Incidents involving radiation sources, such as loss of radioactive sources, damage to radioactive sources and theft of radioactive sources or radiation generators.

2.14. The regulatory body should perform inspection activities relating to the use of nuclear gauges [13]. These inspections should verify that the operating organization is in compliance with the regulatory requirements and with any conditions specified in the authorization. Periodic inspections of facilities and activities should be part of a schedule developed by the regulatory body; in addition, reactive inspections should be conducted in response to a request made by the operating organization, or after an incident. Inspections can be announced or unannounced, as deemed appropriate by the regulatory body. A graded approach should be adopted in the conduct of inspections of facilities and activities such that the frequency and complexity of inspections are commensurate with the radiation risks associated with the facility or activity.

2.15. Inspections should review a range of issues relating to the safe use of nuclear gauges, and should include the following:

(a) Review of compliance with the conditions of the authorization to possess and use nuclear gauges; for example, checking that the inventory includes only those gauges and radiation sources that are authorized, and that gauges are used only for authorized purposes at authorized locations. The temporary use of gauges at client facilities should be subject to specific authorization conditions relating to temporary storage, operation and transport of the gauges. If any authorized source is missing or if any source is found to be not properly authorized, the matter should be investigated and appropriate actions implemented (an immediate search should be performed for missing sources, and any unauthorized sources should be brought under regulatory control).
(b) Confirmation that radiation sources and nuclear gauges meet the acceptance criteria and performance criteria established by the regulatory body.
(c) Measurement of radiation levels around nuclear gauges and confirmation of compliance with authorized levels.
(d) Review of the records of workplace monitoring and of safety assessments performed by the operating organization, to determine whether (and under what circumstances) personal dosimetry is appropriate.
(e) Observing the use of nuclear gauges, including procedures for safe use and, where appropriate, source handling procedures.
(f) Checking the arrangements for the safety and security of each radiation source before the installation of the gauge, during its use and after the end of the useful life of the source.
(g) Review of control measures (e.g. the conduct of periodic source inventory checks, controls to ensure that sources are only used by authorized individuals, use of appropriate engineered controls), storage conditions for portable gauges and for disused sources, and emergency procedures.
(h) Review of compliance with regulatory requirements for transport of radioactive material (see Section 12), especially with regard to the use of portable gauges at client facilities.
(i) Where appropriate, performance of on-site inspections at client facilities where portable gauges are being used.

2.16. Paragraph 2.38 of GSR Part 3 [9] states that: "The regulatory body shall establish, implement, assess and strive to continually improve a management system that is aligned with the goals of the regulatory body and that contributes to the achievement of those goals."

2.17. Requirement 19 of GSR Part 3 [9] states:

> "**The government or the regulatory body shall establish and enforce requirements to ensure that protection and safety is optimized, and the regulatory body shall enforce compliance with dose limits for occupational exposure.**"

The regulatory body should verify that appropriate measures are implemented by the operating organization so that dose limits for occupational exposure and for public exposure are not exceeded. The design requirements for nuclear gauges are stringent and, in general, the radiation levels around nuclear gauges are low. Therefore, while compliance with the dose limits is an important requirement, the main emphasis should be on ensuring that protection and safety is optimized.

2.18. Paragraph 3.69 of GSR Part 3 [9] states that: "The government or the regulatory body shall establish the responsibilities of employers, registrants and licensees with regard to application of the requirements for occupational exposure in planned exposure situations."

2.19. In accordance with para. 3.72 of GSR Part 3 [9], before authorization of a new or modified practice involving a nuclear gauge, the regulatory body should review the design criteria and design features relating to the exposure and potential exposure of workers in all operational states, and in accident conditions. Only nuclear gauges that meet the design standards stipulated by the regulatory body should be permitted to be used. Because of the stringent design standards applicable to nuclear gauges, individual monitoring is expected to be limited to certain types of worker and certain types of gauge (see Section 6). However, in all cases, the regulatory body should verify that the operating organization complies with workplace monitoring requirements (see paras 3.96–3.98 of GSR Part 3 [9]) in all facilities and activities involving nuclear gauges.

2.20. The regulatory body should require that arrangements be made for the safety and security of radioactive sources, including financial provisions, where appropriate, for sources that have become disused. Specifically, the regulatory body should attach conditions to authorizations that require the operating organization to make arrangements for the safe and secure management of disused sources, including, where applicable, agreements regarding the return of disused sources to the supplier, in accordance with the Code of Conduct on the Safety and Security of Radioactive Sources [14].

2.21. The regulatory body should require the operating organization to conduct periodic inventory checks of the radioactive sources in nuclear gauges, and to provide information, as appropriate, to the regulatory body for inclusion in a national register of radioactive sources [14].

2.22. There are certain activities relating to the use of nuclear gauges — such as installation of gauges, removal of gauges from service, and maintenance and repair of gauges — that involve or potentially affect components relating to the safety of the gauge (e.g. the source, source holder, source drive mechanism, shutter, shutter control or shielding). Such activities require specialized training and equipment in order to be performed safely; therefore, these activities are often performed by the gauge manufacturer, source supplier or other service provider. The regulatory body should establish requirements concerning the performance of such activities, which may include requirements for a specific authorization to perform these activities.

THE OPERATING ORGANIZATION

2.23. With regard to nuclear gauges, the operating organization is typically the owner of the industrial facility in which fixed nuclear gauges are installed, or the company undertaking activities with portable nuclear gauges. The operating organization has the prime responsibility for protection and safety (see Requirements 4 and 9 of GSR Part 3 [9]) and is required to ensure that protection and safety is optimized (Requirement 11 of GSR Part 3 [9]). The manufacturers and suppliers of nuclear gauges that contain radiation sources are also operating organizations with their own responsibilities for protection and safety.

2.24. The operating organization is required to demonstrate commitment to protection and safety at the highest levels (para. 2.47 of GSR Part 3 [9]).

2.25. The operating organization is required to submit an application to the regulatory body for authorization to operate a facility or conduct an activity involving nuclear gauges (Requirement 7 of GSR Part 3 [9]). Consequently, for an authorized facility, the operating organization is normally also the licensee or registrant as defined in GSR Part 3 [9].

2.26. As stated in para. 2.42 of GSR Part 3 [9], the operating organization:

> "shall establish and implement a protection and safety programme that is appropriate for the exposure situation. The protection and safety programme:
>
> (a) Shall adopt objectives for protection and safety in accordance with the requirements of [GSR Part 3];
> (b) Shall apply measures for protection and safety that are commensurate with the radiation risks associated with the exposure situation and that are adequate to ensure compliance with the requirements of [GSR Part 3]."

2.27. As stated in para. 2.43 of GSR Part 3 [9], the operating organization:

> "shall ensure that, in the implementation of the protection and safety programme:
>
> (a) The measures and resources that are necessary for achieving the objectives for protection and safety have been determined and are duly provided;
> (b) The programme is periodically reviewed to assess its effectiveness and its continued fitness for purpose;
> (c) Any failures or shortcomings in protection and safety are identified and corrected, and steps are taken to prevent their recurrence;
> (d) Arrangements are made to consult with interested parties;
> (e) Appropriate records are maintained."

Recommendations on establishing a radiation protection programme for nuclear gauges are given in Section 4 of this Safety Guide.

2.28. Paragraph 2.44 of GSR Part 3 [9] states:

> "The relevant principal parties and other parties having specified responsibilities in relation to protection and safety shall ensure that all personnel engaged in activities relevant to protection and safety have appropriate education, training and qualification so that they understand their responsibilities and can perform their duties competently, with appropriate judgement and in accordance with procedures."

Recommendations on the training and qualification of persons working with nuclear gauges are given in Section 5 of this Safety Guide.

2.29. The operating organization is required to allow access by authorized representatives of the regulatory body to conduct inspections of its facilities and activities and of its protection and safety records, and is required to cooperate in the conduct of inspections (para. 2.45 of GSR Part 3 [9]).

2.30. The operating organization is required to ensure that qualified experts (see paras 2.41–2.45) are identified and consulted as necessary on the proper observance of the requirements established in GSR Part 3 (para. 2.46 of GSR Part 3 [9]).

2.31. The operating organization is required to ensure that protection and safety is effectively integrated into its overall management system (Requirement 5 of GSR Part 3 [9]). The management system is required to be commensurate with the radiation risks associated with the number and type of nuclear gauges in the possession of the operating organization (para. 2.49 of GSR Part 3 [9]).

2.32. As stated in para. 2.48 of GSR Part 3 [9], the operating organization (footnote omitted):

> "shall ensure that the management system is designed and applied to enhance protection and safety by:
>
> (a) Applying the requirements for protection and safety coherently with other requirements, including requirements for operational performance, and coherently with guidelines for security;
> (b) Describing the planned and systematic actions necessary to provide adequate confidence that the requirements for protection and safety are fulfilled;
> (c) Ensuring that protection and safety are not compromised by other requirements;
> (d) Providing for the regular assessment of performance for protection and safety, and the application of lessons learned from experience;
> (e) Promoting safety culture."

2.33. As stated in para. 2.50 of GSR Part 3 [9], the operating organization "shall be able to demonstrate the effective fulfilment of the requirements for protection and safety in the management system."

2.34. As stated in para. 3.60 of GSR Part 3 [9], the operating organization "shall ensure that arrangements are made promptly for the safe management of and control over radiation generators and radioactive sources, including appropriate financial provision, once it has been decided to take them out of use." Recommendations on meeting the requirements relating to radiation generators and radioactive sources in nuclear gauges are provided in Section 10 of this Safety Guide.

Safety culture

2.35. Because of the engineered safety features incorporated into the design of nuclear gauges, there is a relatively low reliance on the observance of safe working procedures. Therefore, there is a risk that safety might be taken for granted and that safety culture might not be assigned its due importance in facilities using nuclear gauges. In accordance with para. 2.51 of GSR Part 3 [9], the operating organization should promote and maintain safety culture by doing the following:

(a) Promoting individual and collective commitment to protection and safety at all levels of the organization, including staff responsible for administration, security and storage facilities, as well as workers involved in the operation and maintenance of nuclear gauges.
(b) Ensuring a common understanding of the key aspects of safety culture within the organization.
(c) Supporting individuals and teams in performing their tasks safely and successfully, with account taken of the interactions between individuals, the nuclear gauge technology and the organization. For example, if maintenance work is to be performed in the vicinity of a gauge installation, coordination among the maintenance staff, gauge operating staff and the radiation protection officer is necessary.
(d) Encouraging open communication and participation of gauge operating staff, the radiation protection officer(s) and other workers in the facility in the development and implementation of policies and procedures dealing with protection and safety relating to nuclear gauges.
(e) Ensuring accountability of the organization and of individuals at all levels for protection and safety in the procurement, storage, installation, operation, maintenance, handling and safe management of sources until their safe disposal after the end of their useful life.
(f) Encouraging a questioning and learning attitude, discouraging complacency with regard to protection and safety and providing means by which the organization continually seeks to develop and strengthen its safety culture.

2.36. The operating organization should also ensure that personnel feel free to raise safety concerns without fear of retaliation, intimidation, harassment or discrimination.

Human factors

2.37. Paragraph 2.52 of GSR Part 3 [9] states:

> "The principal parties and other parties having specified responsibilities in relation to protection and safety, as appropriate, shall take into account human factors and shall support good performance and good practices to prevent human and organizational failures, by ensuring among other things that:
>
> (a) Sound ergonomic principles are followed in the design of equipment and the development of operating procedures, so as to facilitate the safe operation and use of equipment, to minimize the possibility that operator errors could lead to accidents, and to reduce the possibility that indications of normal conditions and abnormal conditions could be misinterpreted.
> (b) Appropriate equipment, safety systems and procedural requirements are provided, and other necessary provision is made:
>   (i) To reduce, as far as practicable, the possibility that human errors or inadvertent actions could give rise to accidents or to other incidents leading to the exposure of any person;
>   (ii) To provide means for detecting human errors and for correcting them or compensating for them;
>   (iii) To facilitate protective actions and corrective actions in the event of failures of safety systems or failures of measures for protection and safety."

RADIATION PROTECTION OFFICERS

2.38. Paragraph 3.94(e) of GSR Part 3 [9] states:

> "Employers, registrants and licensees, in consultation with workers or through their representatives where appropriate….Shall designate, as appropriate, a radiation protection officer in accordance with criteria established by the regulatory body."

It should be ensured that any person designated as a radiation protection officer is suitably qualified and trained (see Section 5).

2.39. Paragraph 3.96 of GSR Part 3 [9] states:

> "Registrants and licensees, in cooperation with employers where appropriate, shall establish, maintain and keep under review a programme for workplace monitoring under the supervision of a radiation protection officer or qualified expert."

2.40. The radiation protection officer should be a person technically competent in radiation protection in relation to the use of nuclear gauges, and who is designated by the operating organization to oversee the application of relevant requirements. The appointment of the radiation protection officer should be done in writing and the radiation protection officer's roles and responsibilities should be integrated into the job description.

QUALIFIED EXPERTS

2.41. As stated in para. 2.46 of GSR Part 3 [9], the operating organization "shall ensure that qualified experts are identified and are consulted as necessary on the proper observance of [GSR Part 3]." A qualified expert is an individual who, by virtue of certification by appropriate boards or societies, professional licences or academic qualifications and experience, is duly recognized as having expertise in a relevant field of specialization, for example in radiation protection and the safe operation of nuclear gauges [8].

2.42. The government is required to establish requirements for the formal recognition of qualified experts (para. 2.21 of GSR Part 3 [9]). 'Formal recognition' means documented acknowledgment or accreditation by the relevant authority that a person has the qualifications, training, education, experience and expertise required for the responsibilities that he or she will bear in relation to the use of nuclear gauges [9]. The procedure for formal recognition of qualified experts may vary from State to State.

2.43. The operating organization may consult with one or more qualified experts on matters relevant to radiation safety, such as the design of nuclear gauges and associated facilities, radiation shielding calculations, and testing and maintenance of workplace monitoring instruments. The responsibility for compliance with regulatory requirements cannot be delegated to the qualified expert and always remains with the operating organization.

2.44. Qualified experts do not necessarily have to be employees of the operating organization; they may be appointed on a part time basis or for a specific period or purpose. The qualified expert should satisfy all the requirements for qualification or certification criteria specified by the State where the nuclear gauge is being used and have suitable experience (i.e. with facilities and activities involving nuclear gauges).

2.45. The qualified expert should work in close cooperation with the radiation protection officer to ensure that all the necessary duties and tasks are performed.

WORKERS

2.46. A worker is any person who works, whether full time, part time or temporarily, for an employer and who has recognized rights and duties in relation to occupational radiation protection [8].

2.47. Workers are required to fulfil their obligations and perform their duties for protection and safety (Requirement 22 of GSR Part 3 [9]). In particular, para. 3.83 of GSR Part 3 [9] states:

> "Workers:
>
> (a) Shall follow any applicable rules and procedures for protection and safety as specified by the employer, registrant or licensee;
> (b) Shall use properly the monitoring equipment and personal protective equipment provided;
> (c) Shall cooperate with the employer, registrant or licensee with regard to protection and safety, and programmes for workers' health surveillance and programmes for dose assessment;
> (d) Shall provide to the employer, registrant or licensee such information on their past and present work that is relevant for ensuring effective and comprehensive protection and safety for themselves and others;
> (e) Shall abstain from any wilful action that could put themselves or others in situations that would not be in accordance with the requirements of [GSR Part 3];
> (f) Shall accept such information, instruction and training in protection and safety as will enable them to conduct their work in accordance with the requirements of [GSR Part 3]."

2.48. Paragraph 3.84 of GSR Part 3 [9] states that: "A worker who identifies circumstances that could adversely affect protection and safety shall report such circumstances to the employer, registrant or licensee as soon as possible." Employers should not take adverse or punitive actions against a worker who reports such circumstances.

COOPERATION BETWEEN EMPLOYERS AND REGISTRANTS AND LICENSEES

2.49. Requirement 23 of GSR Part 3 [9] states that: "Employers and registrants and licensees shall cooperate to the extent necessary for compliance by all responsible parties with the requirements for protection and safety." An example of such cooperation is that which is expected to occur between the operating organization using a portable gauge and the client (i.e. the owner of the site on which the gauge is used; see paras 2.56–2.61).

2.50. Paragraph 3.85 of GSR Part 3 [9] states:

> "If workers are engaged in work that involves or that could involve a source that is not under the control of their employer, the registrant or licensee responsible for the source and the employer shall cooperate to the extent necessary for compliance by both parties with the requirements of [GSR Part 3]."

This requirement would apply, for example, in the case of contractors undertaking work close to (but not directly involving) installed nuclear gauges. It would also apply to the use of portable nuclear gauges on sites where there are already other sources of radiation present.

2.51. Paragraph 3.86 of GSR Part 3 [9] states:

> "Cooperation between the employer and the registrant or licensee shall include, where appropriate:
>
> (a) The development and use of specific restrictions on exposure and other means of ensuring that the measures for protection and safety for workers who are engaged in work that involves or could involve a source that is not under the control of their employer are at least as good as those for employees of the registrant or licensee;

(b) Specific assessments of the doses received by workers as specified in (a) above;
(c) A clear allocation and documentation of the responsibilities of the employer and those of the registrant or licensee for protection and safety."

2.52. Paragraph 3.87 of GSR Part 3 [9] states:

"As part of the cooperation between parties, the registrant or licensee responsible for the source or for the exposure as appropriate:

(a) Shall obtain from the employers, including self-employed persons, the previous occupational exposure history of workers…and any other necessary information;
(b) Shall provide appropriate information to the employer, including any available information relevant for compliance with the requirements of [GSR Part 3] that the employer requests;
(c) Shall provide both the worker and the employer with the relevant exposure records."

WORKERS ON SHORT TERM CONTRACTS (ITINERANT WORKERS)

2.53. Operating organizations that hire workers on a short term basis (e.g. using density gauges in connection with construction of roads, bridges) should ensure that such workers have the same level of protection and safety as workers employed on a permanent basis. Such short term workers (sometimes called itinerant workers) typically work for a relatively short period of time (e.g. a few weeks) with the operating organization before leaving to work for another employer. It should be ensured that such working practices are in compliance with regulatory requirements.

2.54. The relevant responsibilities of the operating organization and the itinerant worker should be clearly specified in the contractual arrangements. The operating organization should request information on any occupational exposure received by the itinerant worker, as well as details of any health surveillance up to the time the worker commences work.

2.55. The operating organization and the itinerant worker should fulfil their respective responsibilities, as specified in regulations. The operating organization should clarify with the itinerant worker the allocation of responsibilities for matters such as the following:

(a) The provision of individual dosimetry and dose record keeping, if required (see Section 6);
(b) Health surveillance arrangements, if required (see Section 4);
(c) Workplace monitoring arrangements (see Section 7);
(d) Local rules (see Section 4).

2.56. The operating organization should verify that the itinerant worker has the appropriate qualifications and has received adequate training in both radiation safety and in normal operation as well as in any special procedures he or she will undertake with nuclear gauges. The operating organization should ensure that all procedures and other relevant documents are provided in a language understood by the itinerant worker.

THE CLIENT

2.57. With regard to portable nuclear gauges, the client is the organization or person that hires the operating organization to undertake activities with a nuclear gauge on the client's site. In the case of installed nuclear gauges, the owner of the site or facility is also normally the operating organization. However, the owner of the site or facility can, in some circumstances, also be a client, for example when installation or maintenance work is performed in the facility by specialist nuclear gauge contractors.

2.58. The client should always use an operating organization that is authorized by the regulatory body in accordance with regulatory requirements for nuclear gauges. The operating organization should insist on sufficient time to plan the work and to perform it safely, and to enable compliance with any requirements to notify the regulatory body in advance of the work.

2.59. The operating organization should not accept conditions or limitations that would prevent it from performing activities involving nuclear gauges in a safe manner. The client should ensure that such activities are coordinated with other work on the site, to minimize the risks from site specific hazards and to minimize the radiation exposure of other workers. Arrangements should be made for coordination if more than one operating organization is working on the client's site at one time. A 'permit-to-work' system can facilitate communication and coordination of different activities on the same site.

2.60. The client is responsible for ensuring a safe working environment in locations where access with the portable gauge might be necessary on the site. The client is also responsible for informing workers from the operating organization about safety issues that are site specific, and should provide the visiting workers with any necessary training, in accordance with regulatory requirements.

2.61. If radioactive sources are to be stored temporarily on the client's site, both the client and the operating organization should ensure that the storage arrangements are safe and secure, and that any necessary authorizations are obtained from the regulatory body. Procedures for gaining access to the radioactive source(s) should be clearly defined for the client and the operating organization and adhered to (see also Section 8).

2.62. In the event of an incident involving the gauge with a potential for exposure of individuals to radiation, the client should extend all necessary cooperation to the operating organization to manage the incident in compliance with regulatory requirements (see Section 13).

3. SAFETY ASSESSMENT

GENERAL

3.1. Requirement 13 of GSR Part 3 [9] states:

> "**The regulatory body shall establish and enforce requirements for safety assessment, and the person or organization responsible for a facility or activity that gives rise to radiation risks shall conduct an appropriate safety assessment of this facility or activity.**"

Requirements for safety assessment are established in IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [15].

3.2. Some of the radiation sources used in nuclear gauges can produce high dose rates and hence should be subject to a comprehensive safety assessment. Nuclear gauges containing radioactive material that is of low activity (and which is above the exemption levels specified by the regulatory body) should also be subject to a safety assessment, but in this case the safety assessment is expected to be much more straightforward, applying a graded approach commensurate with the magnitude of exposure. For nuclear gauges of an identical type, it might be acceptable to conduct a generic safety assessment.

3.3. The initial safety assessment, sometimes called a ‘prior radiological evaluation’, is the primary tool for determining which control measures should be taken, and for confirming that all factors that have a bearing on protection and safety are considered. In accordance with Requirement 13 of GSR Part 3 [9], the safety assessment is required to be documented and, where appropriate, independently reviewed within the operating organization’s management system.

3.4. Prospective users of nuclear gauges should submit a safety assessment to the regulatory body when applying for an authorization; therefore, the safety assessment should be prepared and documented before the nuclear gauge is received by the operating organization. Suppliers of nuclear gauges should seek an appropriate authorization before marketing gauges in a State, in accordance with the regulatory requirements of the State.

3.5. The operating organization should plan ahead, to ensure that there is sufficient time for the required control measures for protection and safety to be established and applied. A new safety assessment might not be necessary when a source in a nuclear gauge has been replaced with a source of an identical type unless there are changes in the working arrangements, for example a significant increase in occupancy of the area around the gauge installation.

3.6. In the case of work being conducted for which no safety assessment has been made, the operating organization should perform and document a retrospective safety assessment. On the basis of the retrospective safety assessment, either it should be confirmed that all the necessary control measures are in place, or else additional control measures should be identified and implemented.

METHODOLOGY FOR THE SAFETY ASSESSMENT

3.7. For nuclear gauges, the safety assessment should include consideration of the following:

(a) The dose rates from shielded and unshielded radioactive sources and from radiation generators (X ray and neutron), as appropriate;
(b) The exposure of workers and the public from normal operation of nuclear gauges, and potential exposures from reasonably foreseeable incidents

(including exposures due to loss or reduction of radiation shielding incorporated in the design of the nuclear gauge, due to contamination from a damaged radioactive source, and from other scenarios, including very low probability events);
(c) Limits and technical conditions for operation of the nuclear gauge(s);
(d) Ways in which structures, systems and components, as well as procedures relating to protection and safety, might fail or might otherwise lead to potential exposures, and the consequences of such failures or potential exposures;
(e) Ways in which external factors, operating errors and human factors could affect protection and safety;
(f) The implications of any proposed modifications for protection and safety;
(g) Any uncertainties or assumptions, and their implications for protection and safety.

Further considerations for a safety assessment for nuclear gauges are provided in Annex II.

OUTCOMES OF THE SAFETY ASSESSMENT

3.8. The safety assessment should be used by the operating organization to provide a basis for decision making in relation to the following:

(a) The engineered control measures that are necessary for safety, for example to prevent access to the primary beam of a nuclear gauge.
(b) The administrative controls that are necessary for safety, for example the procedures required to control entry into vessels on which level gauges are installed, particularly when the shutter is open.
(c) The development of safe working procedures (local rules) for storage, operation, maintenance of a source inventory, servicing and maintenance, and management of disused sources.
(d) Procedures for designating controlled areas and supervised areas (permanent and temporary).
(e) Any measures necessary for the protection of the public.
(f) The assessment of occupational exposures (see Section 6).
(g) The training programme for gauge users and other persons (see Section 5).
(h) An effective emergency preparedness and response programme to manage reasonably foreseeable events (including very low probability events). This should include: information on reasonably foreseeable incidents, the measures necessary to prevent or minimize the likelihood of occurrence

of such incidents, and the necessary emergency response arrangements (including emergency plans and procedures, and emergency equipment) (see Section 13).

(i) The security of radioactive sources in fixed gauges and portable gauges, with the objective of deterring, detecting, delaying and responding to the theft of sources (see Section 9).

REVIEWS OF THE SAFETY ASSESSMENT

3.9. The safety assessment should be reviewed annually and whenever any of the following factors apply:

(a) When safety might be compromised or affected as a result of modifications to facilities or to activities;
(b) When the acquisition of a new radiation source or a source with different characteristics is planned;
(c) When operating experience or the investigation of incidents, failures or errors indicates that current safety measures are invalid or are not fully effective;
(d) When significant changes to relevant standards, regulations or guidance have been made or are envisaged.

3.10. The operating organization should ensure that the safety assessment reflects current working practices and that no changes have been overlooked.

RECORD OF THE SAFETY ASSESSMENT

3.11. The safety assessment should be documented and independently reviewed within the operating organization's management system. Revisions and modifications of the safety assessment should be subject to audit by the regulatory body.

GRADED APPROACH

3.12. A graded approach in relation to a regulatory system or a safety system is a process or method in which the stringency of the control measures and conditions to be applied is commensurate, to the extent practicable, with the likelihood and possible consequences of, and the level of risk associated with, a loss of control [8]. The regulatory body should adopt a graded approach to the implementation of the system of protection and safety, such that the application of regulatory requirements is commensurate with the radiation risks associated with the exposure situation.

3.13. For fixed nuclear gauges there might be large numbers of workers routinely present in the immediate area; however, the radiation risk is normally very low. In contrast, when using portable nuclear gauges the number of workers present is often lower but the potential to receive occupational exposures is higher. These factors should be taken into account when developing and performing the safety assessment.

OPTIMIZATION OF PROTECTION AND SAFETY

3.14. The safety assessment should take into account that the magnitude of the individual doses, the number of people exposed and the likelihood of incurring potential exposures are all to be kept as low as reasonably achievable, economic and societal factors being taken into account. Any interaction between these various factors should be taken into account. If the next step of reducing the detriment can be achieved only by deploying resources disproportionate to the expected benefits, it might not be appropriate to take that step, provided that individuals have been adequately protected. Optimization is an iterative process and should also be applied when an existing practice is being reviewed [16].

3.15. Owing to shielding and other safety features, the radiation exposures associated with the use of nuclear gauges are expected to be low, especially for installed gauges. In many cases, there is no need to provide additional engineered safety features, which would entail an additional expenditure for no significant reduction in the radiation risk.

4. RADIATION PROTECTION PROGRAMME

OBJECTIVES AND SCOPE

4.1. Requirement 24 of GSR Part 3 [9] states:

> “**Employers, registrants and licensees shall establish and maintain organizational, procedural and technical arrangements for the designation of controlled areas and supervised areas, for local rules and for monitoring of the workplace, in a radiation protection programme for occupational exposure.**”

4.2. Paragraph 3.93 of GSR Part 3 [9] states:

> “Employers, registrants and licensees shall minimize the need to rely on administrative controls and personal protective equipment for protection and safety by providing well engineered controls and satisfactory working conditions, in accordance with the following hierarchy of preventive measures:
>
> (1) Engineered controls;
> (2) Administrative controls;
> (3) Personal protective equipment.”

4.3. The radiation protection programme is a key factor in relation to the development and maintenance of safety culture within an organization. The radiation protection programme should cover the operating organization’s management structure, policies, responsibilities, procedures and organizational arrangements. All of these should be put in place by the operating organization to control radiation hazards and to optimize protection and safety. Detailed recommendations on establishing and maintaining a radiation protection programme for the protection of workers are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [17].

4.4. The radiation protection programme should be customized and scaled to meet the needs of the operating organization. The programme should reflect the complexities and hazards associated with the nuclear gauge facilities and activities. The programme should be based on the operating organization’s safety assessment (see Section 3), and it should address planned exposure situations and, as appropriate, emergency exposure situations (see Section 13).

4.5. The operating organization should take into account any additional measures and programmes necessary to address other workplace hazards, which might include one or several of the following:

(a) Chemical hazards;
(b) Fire and explosion;
(c) Noise and vibration;
(d) Mechanical hazards (e.g. lifting equipment, rollers);
(e) Heat (e.g. furnaces, ovens);
(f) Hazards relating to pressure vessels.

STRUCTURE AND CONTENT

4.6. The radiation protection programme should cover the main elements contributing to protection and safety. The structure and content of the radiation protection programme should be documented to an appropriate level of detail, and should address the following essential elements:

(a) The management structure and policies relevant to protection and safety;
(b) The assignment of individual responsibilities for protection and safety;
(c) A training programme on the nature of the radiation hazards, and on the measures required for protection and safety;
(d) Local rules and the arrangements for supervision of the work with nuclear gauges;
(e) The designation of controlled areas and supervised areas, as appropriate;
(f) Safety and security of radioactive sources including management of disused sources;
(g) Emergency preparedness and response;
(h) The arrangements for assessing occupational exposure (if required) and for monitoring the workplace, including the acquisition, testing and maintenance of workplace monitoring instruments;
(i) The programme for health surveillance of workers (if required);
(j) A system for recording and reporting information relating to the control of exposures, the decisions regarding measures for occupational radiation protection and safety, and the results of individual monitoring and workplace monitoring;
(k) Methods for periodically reviewing and auditing the performance of the radiation protection programme;
(l) Requirements for quality assurance and procedures for process improvement.

4.7. These elements of a radiation protection programme, which are more fully described in the following sections, can be incorporated into a single document or a series of documents, depending on the scale and complexity of operations. The radiation protection programme, or a summary of it, should be made available to workers.

MANAGEMENT STRUCTURE AND POLICIES

4.8. The radiation protection programme should include a description of the management structure as it relates to protection and safety. This structure could be represented in the form of an organizational chart. This chart should clearly show the lines of reporting, from workers to the senior managers with overall responsibility, and should list the names and contact details of persons with specific responsibilities for protection and safety (e.g. the radiation protection officer; see Section 2). If the operating organization has more than one location of operations, the management structure should clearly specify the lines of responsibility and the responsible persons at each location.

4.9. The radiation protection programme should include the operating organization's policies on radiation protection and safety, and should include a commitment by the management to keeping radiation doses as low as reasonably achievable and to fostering a positive safety culture.

PROGRAMME OF EDUCATION AND TRAINING

4.10. The radiation protection programme should describe the scope of the training programme in protection and safety for all workers directly involved in activities with nuclear gauges, including any associated emergency response actions. It should also include a 'radiation awareness' programme for other staff, where appropriate. Such staff include managers and general workers (i.e. individuals who are not working directly with nuclear gauges). The radiation protection programme should also specify the minimum educational and professional qualifications for relevant staff, especially the radiation protection officer and personnel involved in gauge installation and maintenance, in accordance with regulatory requirements. Section 5 provides more details on training and qualification of personnel.

4.11. The operating organization should keep suitable training records, consistent with regulatory requirements. The record keeping arrangements should be specified in the radiation protection programme.

LOCAL RULES AND SUPERVISION

4.12. Paragraph 3.94 of GSR Part 3 [9] states:

> "Employers, registrants and licensees, in consultation with workers, or through their representatives where appropriate:
>
> (a) Shall establish in writing local rules and procedures that are necessary for protection and safety for workers and other persons;
> (b) Shall include in the local rules and procedures any relevant investigation level or authorized level, and the procedures to be followed in the event that any such level is exceeded;
> (c) Shall make the local rules and procedures and the measures for protection and safety known to those workers to whom they apply and to other persons who may be affected by them;
> (d) Shall ensure that any work in which workers are or could be subject to occupational exposure is adequately supervised and shall take all reasonable steps to ensure that the rules, procedures, and measures for protection and safety are observed;
> (e) Shall designate, as appropriate, a radiation protection officer in accordance with criteria established by the regulatory body."

4.13. Local rules that describe the procedures for performing work with nuclear gauges should be written in a language that is understood by the workers who are expected to follow the rules. These local rules should cover all procedures associated with nuclear gauges where there is the potential for radiation exposure, such as installation, routine operations, source exchange, transport of radioactive sources, maintenance operations, cessation of use and disposal, as well as the procedures for emergency response (see Sections 8, 11, 12 and 13). The local rules are an important tool in the restriction of radiation doses. They should include sufficient information to allow workers to perform their duties safely and in compliance with regulatory requirements.

4.14. A copy of the local rules should be provided to workers undertaking activities involving nuclear gauges and to other relevant persons; additional copies should be displayed in the work area, as appropriate. Managers should ensure that all relevant persons have read and understood the local rules.

4.15. In organizations with a small number of gauges of a similar type, it might be appropriate to have one set of local rules covering all procedures. In larger organizations, especially those with a range of different gauging applications, it might be more appropriate to have several sets of specific local rules.

4.16. Local rules should be provided for specific procedures, such as for performing work with portable nuclear gauges, and for exchanging radioactive sources in installed gauges. Some client organizations might also request specific local rules to be drawn up to cover gauging work on their premises.

4.17. The operating organization is required to designate a radiation protection officer (see Section 2), and may appoint more than one qualified employee as radiation protection officer to oversee the day to day implementation of the local rules and to perform other duties as required in the radiation protection programme.

4.18. A sample table of contents for local rules is provided in Table II–2 of Annex II.

RADIATION SAFETY COMMITTEE

4.19. A radiation safety committee should be established in larger organizations that have a significant number of nuclear gauges or gauging applications, for the purpose of regularly reviewing the implementation of the radiation protection programme. This committee might be dedicated to radiation safety or it might also have other (conventional) safety related responsibilities. The radiation safety committee should include the radiation protection officer; health, safety and environment officers; servicing and maintenance engineers and security officers. The committee should also include the senior manager(s) responsible for radiation safety, and representatives of the workforce. The responsibilities of the radiation safety committee should include the following:

(a) Regular reviews of the radiation protection programme;
(b) Reviews of occupational radiation doses, workplace monitoring programme results and any incident reports prepared by the radiation protection officer;
(c) Reviews of results of audits on the performance of the radiation protection programme;
(d) Making recommendations to senior management for improvements in the radiation protection programme;
(e) Provision of guidance and direction on the performance of the radiation protection officer’s duties;
(f) Monitoring the investigation of any incident with the potential for unplanned exposure to radiation;

(g) Preparation of reports about relevant radiation safety issues, and dissemination to managers and workers, as appropriate.

DESIGNATION OF CONTROLLED AREAS AND SUPERVISED AREAS

4.20. Paragraph 3.88 of GSR Part 3 [9] states (footnote omitted):

> "Registrants and licensees shall designate as a controlled area any area in which specific measures for protection and safety are or could be required for:
>
> (a) Controlling exposures or preventing the spread of contamination in normal operation;
> (b) Preventing or limiting the likelihood and magnitude of exposures in anticipated operational occurrences and accident conditions."

4.21. Paragraph 3.89 of GSR Part 3 [9] states:

> "In defining the boundaries of any controlled area, registrants and licensees shall take account of the magnitude of the exposures expected in normal operation, the likelihood and magnitude of exposures in anticipated operational occurrences and in accident conditions, and the type and extent of the procedures required for protection and safety."

With regard to nuclear gauges, the locations where the gauges are installed (or areas where mobile gauges are used), and any enclosures where gauges or sources are stored, might need to be designated as controlled areas.

4.22. Paragraph 3.90 of GSR Part 3 [9] states:

> "Registrants and licensees:
>
> (a) Shall delineate controlled areas by physical means or, where this is not reasonably practicable, by some other suitable means.
> (b) Shall, where a source is only intermittently brought into operation or energized, or is moved from place to place, delineate an appropriate controlled area by means that are appropriate under the prevailing circumstances and shall specify exposure times.
> (c) Shall display the symbol recommended by the International Organization for Standardization [18] and shall display instructions at access points to and at appropriate locations within controlled areas.

(d) Shall establish measures for protection and safety, including, as appropriate, physical measures to control the spread of contamination and local rules and procedures for controlled areas.
(e) Shall restrict access to controlled areas by means of administrative procedures such as the use of work permits, and by physical barriers, which could include locks or interlocks, the degree of restriction being commensurate with the likelihood and magnitude of exposures.

…….

(h) Shall periodically review conditions to assess whether there is any need to modify the measures for protection and safety or the boundaries of controlled areas[.]
(i) Shall provide appropriate information, instruction and training for persons working in controlled areas."

4.23. As stated in para. 3.91 of GSR Part 3 [9]:

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

4.24. The radiation protection programme should describe how controlled areas and supervised areas are to be designated. It should also describe the arrangements for delineating and restricting access to designated areas, the use of warning signs and the radiation monitoring programme.

4.25. The designation of controlled areas and supervised areas should be based on the safety assessment (see Section 3), in particular on the dose rates in the workplace. Dose rates in the main beam of a nuclear gauge can be high, and where access to the beam is possible, the area should normally be designated as a controlled area.

4.26. Fixed nuclear gauges designed to meet performance standards specified in IEC 62598 [12] should be procured and installed in such a way that there is no need to designate a controlled area around the outside of the gauge installation. Depending on the dose rate, the surrounding area might be designated as a supervised area.

PROGRAMME OF WORKPLACE MONITORING

4.27. The radiation protection programme should describe the arrangements put in place by the operating organization for the selection, calibration, maintenance, testing and use of workplace monitoring equipment to measure the dose rates around nuclear gauges. The radiation protection programme should specify the locations where dose rate measurements around installed gauges and around portable gauges should be made and the frequency of such measurements. The programme should also describe the arrangements for recording the monitoring results and the length of time for which the records should be retained, in accordance with regulatory requirements.

4.28. The radiation protection programme should specify suitable radiation monitors and the number of monitors that should be available. When using portable gauges for site work, a radiation monitor should always be available. For sites with stationary gauges, it is often sufficient to have one monitor in use and one available as a backup.

4.29. The radiation protection programme should include dose rate investigation levels, as recommended in GSG-7 [17]. These investigation levels should represent the maximum dose rates that are acceptable, either around a gauge installation or during the performance of specific tasks. Such dose rate investigation levels should be consistent with regulatory requirements and guidance.

4.30. The arrangements for workplace monitoring for nuclear gauges are described in more detail in Section 7.

ARRANGEMENTS FOR INDIVIDUAL MONITORING

4.31. The safety assessment (see Section 3) should determine whether the assessment of occupational exposures by individual monitoring (see Section 6) is required. If it is required, the radiation protection programme should specify which workers are to be subject to individual monitoring, the types of dosimeter to be used, when the dosimeters are to be worn, and the arrangements for the assessment of dosimeters and for dose record keeping. The radiation protection programme should also specify that the dosimetry service provider should be appropriately approved or accredited. The radiation protection programme should provide guidance to the radiation protection officer on reviewing the dose records periodically to identify doses that are higher than usual and determining whether doses are as low as reasonably achievable.

HEALTH SURVEILLANCE PROGRAMME

4.32. The safety assessment (see Section 3) should determine whether a health surveillance programme for persons working with nuclear gauges is required, in accordance with Requirement 25 of GSR Part 3 [9] and with regulatory requirements. If health surveillance is required, the radiation protection programme should include details of the arrangements for workers. This should include the assessment of the initial fitness and the continuing fitness of workers for their intended tasks. A qualified expert and/or an appropriately qualified occupational physician should be consulted regarding the establishment of the programme for health surveillance, which should be consistent with regulatory requirements.

4.33. Medical examinations of occupationally exposed workers should follow the general principles of occupational medicine and should be conducted by an occupational physician. Each worker covered by the health surveillance programme should be subject to a medical examination before commencing work with radiation, and thereafter at specified intervals, in accordance with regulatory requirements.

4.34. The initial medical examination should assess the health of workers and their fitness for the intended tasks, and should also identify those workers who have a condition that might necessitate particular precautions during work.

4.35. Periodic medical examinations should focus on confirming that no clinical condition has developed that could prejudice the health of the worker while he or she is working in areas involving occupational health hazards, including radiation [17]. The nature and frequency of the periodic medical examination should depend on the type of work that is undertaken, the age and health status — and possibly the habits (e.g. smoking) — of the worker and other considerations that may be specified in the regulations. The frequency of periodic medical examinations should be determined on the basis of the state of health of the worker and the type of work he or she undertakes, but should typically be once a year.

4.36. Medical records associated with the health surveillance programme should be confidential and should be preserved in a manner approved by the regulatory body. Such records should normally be retained for the lifetimes of the workers concerned.

4.37. Health surveillance can also provide a baseline of information that can be used in the event of accidental exposure to a particular hazardous agent or in the event of occupational disease, and to provide workers with access to counselling with respect to any radiation risks to which they are or might be subjected.

PERIODIC REVIEWS AND AUDITS OF THE PERFORMANCE OF THE RADIATION PROTECTION PROGRAMME

4.38. As an integral part of the operating organization's management system, the radiation protection programme and its implementation should be reviewed on an annual basis. This periodic review should aim to identify problems and make recommendations to improve the effectiveness of the radiation protection programme.

4.39. A key part of this periodic review process is a series of workplace audits. The operating organization should specify the designation and qualifications of the persons who will conduct these audits, the frequency of the audits, the expectations of the audit team, and the procedures for the reporting of results and their follow-up.

MANAGEMENT SYSTEM AND PROCESS IMPROVEMENT

4.40. Work with nuclear gauges should be performed in accordance with an established management system. This management system should be designed to ensure that all equipment and safety systems are regularly checked and tested, and that any faults or deficiencies are promptly brought to the attention of the management and quickly remedied.

4.41. The management should ensure that the correct operating procedures and local rules are being followed, and that the management system specifies the relevant checks and audits to be made and the records to be kept. The relevant regulatory requirements should be taken into account and reflected in the management system.

4.42. The management system should include a mechanism for the collection and feedback of lessons from incidents (including those reported within the organization and by other organizations), and how these lessons can be used to enhance safety.

4.43. The management system should itself be reviewed and updated as necessary with reference to pre-identified performance indicators.

5. TRAINING AND QUALIFICATION OF PERSONS WORKING WITH NUCLEAR GAUGES

GENERAL

5.1. The operating organization is responsible for ensuring that work with nuclear gauges is performed safely and in compliance with all relevant regulations and safety standards. The operating organization should, therefore, ensure that such work is performed only by staff who are suitably qualified or certified, and who are competent and trained in working with nuclear gauges as well as in protection and safety.

5.2. The programmes for the training and qualification of persons working with nuclear gauges vary in scope and detail. In some cases, they might include only a limited amount of training in radiation safety. In such cases, training programmes should be supplemented with appropriate additional training in protection and safety specific to nuclear gauges for relevant persons. Such additional training may be provided by specialized training organizations rather than by the operating organization. Training courses in protection and safety may be provided by a range of training providers, including colleges, universities, radiation protection institutions and training consultants [19].

DESIGN OF A TRAINING PROGRAMME

5.3. Nuclear gauge personnel can be classified according to the required levels of competence in protection and safety, as follows:

— Level 1: Personnel working in a supervised area.
— Level 2: Personnel working with radiation sources (e.g. engaged in handling, transport, calibration, assembly and installation of gauges) and/or working in controlled areas.

5.4. Training programmes should be established for the different levels of competence and should correspond to the roles and responsibilities of the workers. The training programme should include the criteria for passing written and practical examinations, where these are considered appropriate, as well as the procedures to be followed if an applicant fails an examination. The details of the training programme should be incorporated into the radiation protection programme.

STRUCTURE AND CONTENT OF THE TRAINING COURSE

5.5. Each training course should be structured around specific aims and objectives and should be customized to the needs of the target audience [19]. A summary of the essential elements for basic training in radiation safety for level 2 nuclear gauge personnel is provided in Table 1.

5.6. Actual nuclear gauge sources should not be used in this training. If needed, training devices are available that simulate radioactive sources and associated radiation monitoring equipment. An alternative (e.g. for persons who assemble gauges) is to use 'dummy' sources that are not radioactive.

TABLE 1. SUMMARY OF THE ESSENTIAL ELEMENTS FOR BASIC TRAINING IN RADIATION SAFETY FOR LEVEL 2 NUCLEAR GAUGE PERSONNEL

Fundamental concepts and measurements	Basic concepts of ionizing radiation Source outputs and effects of time, distance and shielding Radiation quantities and units Biological effects of ionizing radiation
Principles of radiation protection	System of radiation protection: Justification of practices Optimization of protection and safety Dose limitation
Practical radiation protection	Regulatory requirements Management of radiation protection Safety assessment and engineered control measures The radiation protection programme Designation of controlled areas and supervised areas Local rules Working practices to optimize protection and safety Individual monitoring Workplace monitoring Storage of radioactive sources Correct operation and maintenance of gauging equipment Transport of radioactive sources Cessation of use and disposal of disused radioactive sources Incidents involving nuclear gauges, their consequences and lessons identified Security of radioactive material General security measures and security plan Emergency preparedness and response

5.7. Section 13 provides recommendations on training and exercises in emergency preparedness and response.

5.8. The security of radioactive material should be an integral part of the training programme for persons working with nuclear gauges containing radioactive sources.

REFRESHER TRAINING

5.9. The operating organization should arrange for a programme of refresher training for nuclear gauge personnel to ensure that their knowledge and skills are kept up to date. Such training should include a review of the fundamentals of protection and safety, and information on any changes to safety standards, equipment, policies and procedures, and any changes in regulatory requirements.

5.10. The frequency of refresher training should be consistent with regulatory requirements. This refresher training could be combined with other refresher training programmes relevant to the same workers. A typical frequency for refresher training is every three to five years; however, significant changes in regulations or the occurrence of safety issues should be disseminated as written instructions as soon as practicable, and then followed up by inclusion in the next scheduled refresher training.

TRAINING ASSESMENTS AND CERTIFICATION

5.11. Written examinations and practical training sessions on the handling of radiation sources in nuclear gauges should be conducted for level 2 personnel (see para. 5.3).

6. INDIVIDUAL MONITORING OF WORKERS

GENERAL

6.1. Paragraph 3.99 of GSR Part 3 [9] states:

> "Employers, as well as self-employed persons, and registrants and licensees shall be responsible for making arrangements for assessment of the occupational exposure of workers, on the basis of individual monitoring where appropriate, and shall ensure that arrangements are made with authorized or approved dosimetry service providers that operate under a quality management system."

6.2. Paragraph 3.100 of GSR Part 3 [9] states (footnote omitted):

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

Dose assessment based on workplace monitoring should be performed by the radiation protection officer or a qualified expert.

6.3. The results of workplace monitoring can be used to indirectly estimate the radiation dose to workers, and this will often be appropriate for many workers in facilities where nuclear gauges are installed. In some situations, however, it will be more appropriate for workers to wear personal dosimeters to directly assess their individual dose. This might be the case for workers performing maintenance on nuclear gauges or workers routinely using portable gauges.

6.4. Where individual monitoring is considered appropriate, the operating organization should ensure that radiation doses to designated nuclear gauge personnel are assessed to ensure that doses are kept as low as reasonably achievable and are below the dose limits (see paras 6.5–6.10). The results from the assessment of doses can also highlight good or bad working practices, faulty equipment, or the degradation of shielding or other engineered safety systems.

DOSE LIMITS FOR OCCUPATIONAL RADIATION PROTECTION

6.5. Paragraph 3.26 of GSR Part 3 [9] states that: "The government or the regulatory body shall establish and the regulatory body shall enforce compliance with the dose limits specified in Schedule III [of GSR Part 3] for occupational exposures and public exposures in planned exposure situations."

6.6. Paragraph 3.27 of GSR Part 3 [9] states:

> "The government or the regulatory body shall determine what additional restrictions, if any, are required to be complied with by registrants and licensees to ensure that the dose limits specified in Schedule III [of GSR Part 3] are not exceeded owing to possible combinations of doses from exposures due to different authorized practices."

6.7. Paragraph 3.28 of GSR Part 3 [9] states (footnote omitted):

> "Registrants and licensees shall ensure that the exposures of individuals due to the practices for which the registrants and licensees are authorized are restricted, so that neither the effective dose nor the equivalent dose to tissues or organs exceeds any relevant dose limit specified in Schedule III [of GSR Part 3]."

6.8. Paragraph III.1 of GSR Part 3 [9] states:

> "For occupational exposure of workers over the age of 18 years, the dose limits are:
>
> (a) An effective dose of 20 mSv per year averaged over five consecutive years[66] (100 mSv in 5 years) and of 50 mSv in any single year;
> (b) An equivalent dose to the lens of the eye of 20 mSv per year averaged over five consecutive years (100 mSv in 5 years) and of 50 mSv in any single year;
> (c) An equivalent dose to the extremities (hands and feet) or to the skin[67] of 500 mSv in a year.
>
> Additional restrictions apply to occupational exposure for a female worker who has notified pregnancy or is breast-feeding" (see section 6 of GSG-7 [17]).

“[66] The start of the averaging period shall be coincident with the first day of the relevant annual period after the date of entry into force of [GSR Part 3], with no retrospective averaging.

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

6.9. Paragraph III.2 of GSR Part 3 [9] states:

“For occupational exposure of apprentices of 16 to 18 years of age who are being trained for employment involving radiation and for exposure of students of age 16 to 18 who use sources in the course of their studies, the dose limits are:

(a) An effective dose of 6 mSv in a year;
(b) An equivalent dose to the lens of the eye of 20 mSv in a year;
(c) An equivalent dose to the extremities (hands and feet) or to the skin[67] of 150 mSv in a year.

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

6.10. Short term contract workers are subject to the same dose limits as permanently employed workers.

INDIVIDUAL DOSE ASSESSMENT USING PASSIVE DOSIMETERS

6.11. The operating organization should make arrangements with a dosimetry service for the provision of suitable dosimeters to those workers for whom individual dosimetry is considered appropriate, for dose assessment and dose record keeping. The dosimeters should be worn by all workers who are required to regularly enter controlled areas (and also supervised areas, where this is required by national regulations).

6.12. The choice of type of dosimeter to be used should be evaluated by the radiation protection officer, possibly in conjunction with a qualified expert in radiation dosimetry. In addition to the need to meet various technical requirements, the choice of dosimeter might also be influenced by considerations of availability, cost and robustness, as well as regulatory requirements.

6.13. To ensure that the dosimeter provides an accurate assessment of the effective dose to the worker, the following guidelines should be followed:

(a) Dosimeters should be worn by relevant personnel at all times when performing work with radiation sources.
(b) Dosimeters should be worn in accordance with the recommendations of the dosimetry service provider.
(c) For passive dosimeters (e.g. thermoluminescent, optically stimulated luminescent and film dosimeters), the measuring element should be correctly positioned in the dosimeter holder.
(d) The dosimeter should be worn only by the person to whom it is issued.
(e) Care should be taken to avoid damaging the measuring element of the dosimeter (dosimeters can be damaged by water, high temperature, high pressure or physical impact).
(f) Dosimeters should not be exposed to radiation when not being worn by the worker (the dosimeter should be stored away from sources of radiation when not in use).
(g) Passive dosimeters should be promptly processed by the dosimetry service at the end of the period of wear. Dosimeters that have been returned early owing to a suspicion of abnormal exposure should be processed urgently.
(h) The dosimetry service should be informed if the operating organization suspects that the dosimeter has been damaged or has been exposed to radiation while the worker to whom it was assigned was not wearing it, in order that the correct dose to be assigned to the worker can be determined.
(i) Neutron dosimeters with a suitable neutron energy response should be worn by personnel who receive occupational exposures from working with nuclear gauges containing neutron sources or neutron generators.

ACTIVE PERSONAL DOSIMETERS

6.14. Active personal dosimeters are small electronic radiation detectors that emit a warning signal when a pre-set dose rate or dose alarm level is exceeded. Most of these devices also provide a digital display of the cumulative personal dose equivalent. The warning signal is normally an audible alarm, although this can be supplemented by a vibration or a visual signal, which is useful if the ambient noise level is high or if hearing protection devices are being worn.

6.15. Active personal dosimeters are a useful tool to warn of high dose rates or to prevent overexposures. They can help to immediately alert workers to problems, hence preventing incidents or mitigating their consequences. The operating organization should consider providing active personal dosimeters especially if procedures that involve the direct handling of sources (such as gauge assembly or maintenance) are to be performed.

6.16. Important considerations in relation to the use of active personal dosimeters include the following:

(a) Active personal dosimeters should not be used as a replacement for workplace monitoring instruments (e.g. dose rate meters).
(b) Active personal dosimeters should be tested periodically in accordance with national recommendations and guidance from the manufacturer.
(c) Active personal dosimeters should be calibrated in terms of the radiation fields likely to be encountered in the workplace.
(d) Alarm settings of the active personal dosimeters should reflect an appropriate level of dose and/or dose rate and the alarm level should be visible during operation of the device.
(e) Changes to active personal dosimeters should not be allowed, except by persons with appropriate roles and responsibilities.

RECORD KEEPING

6.17. Paragraph 3.103 of GSR Part 3 [9] states that (footnote omitted): "Employers, registrants and licensees shall maintain records of occupational exposure for every worker for whom assessment of occupational exposure is required…"

6.18. The operating organization should keep records of doses received by nuclear gauge personnel who regularly enter controlled areas (and also supervised areas, where this is required by national regulations). These records should contain details of the doses recorded by the dosimeters worn by workers. If possible, the records should clearly identify any doses received as a result of incidents or while following emergency procedures, as distinct from doses received during routine work.

6.19. The records should reflect the doses recorded by the worker's primary individual dosimeter issued by the dosimetry service, rather than the doses measured by other devices such as active personal dosimeters.

6.20. Paragraph 3.106 of GSR Part 3 [9] states:

> "Employers, registrants and licensees:
>
> (a) Shall provide workers with access to records of their own occupational exposure;
> (b) Shall provide the supervisor of the programme for workers' health surveillance, the regulatory body and the relevant employer with access to workers' records of occupational exposure;
> (c) Shall facilitate the provision of copies of workers' exposure records to new employers when workers change employment;
> (d) Shall make arrangements for the retention of exposure records for former workers by the employer, registrant or licensee, as appropriate;
> (e) Shall, in complying with (a)–(d) above, give due care and attention to maintaining the confidentiality of records."

6.21. Paragraph 3.104 of GSR Part 3 [9] states:

> "Records of occupational exposure for each worker shall be maintained during and after the worker's working life, at least until the former worker attains or would have attained the age of 75 years, and for not less than 30 years after cessation of the work in which the worker was subject to occupational exposure."

6.22. Paragraph 3.107 of GSR Part 3 [9] states:

> "If employers, registrants and licensees cease to conduct activities in which workers are subject to occupational exposure, they shall make arrangements for the retention of workers' records of occupational exposure by the regulatory body or a State registry, or by a relevant employer, registrant or licensee, as appropriate."

INVESTIGATION OF DOSES EXCEEDING DOSE LIMITS

6.23. The operating organization is required to conduct an investigation if a radiation dose to a worker or a member of the public exceeds any dose limit or an investigation level specified by the regulatory body or operating organization (Requirement 16 of GSR Part 3 [9]). The investigation should focus on the causes that resulted in the exposure, and on any contributing failures in procedures or safety systems. The investigation report should identify any improvements to procedures or facilities to optimize protection and safety, to reduce the likelihood of a similar event occurring and to mitigate the consequences.

6.24. Recommendations on the notification and reporting of incidents are provided in Section 13.

DOSIMETRY EQUIPMENT TESTING AND CALIBRATION

6.25. Dosimeters should be of an approved type and should be subjected to periodic quality assurance tests. Personal dosimetry systems should be calibrated periodically (typically every one or two years), with more frequent checks being conducted on the performance of the system. National regulations may require different frequencies of calibration. Recommendations on the testing and calibration of dosimeters and dosimetry equipment are provided in GSG-7 [17].

7. WORKPLACE MONITORING

MONITORING PROGRAMME

7.1. Paragraph 3.96 of GSR Part 3 [9] states that: "Registrants and licensees… shall establish, maintain and keep under review a programme for workplace monitoring under the supervision of a radiation protection officer or qualified expert."

7.2. The programme for workplace monitoring should be designed to assess the adequacy of the arrangements in place for protection and safety for facilities and activities involving nuclear gauges. The programme should include measurements of dose rate at the following positions:

(a) Around storage facilities for gauges and sources, to ensure that an adequate level of shielding is provided;

(b) Around gauges during routine operations, to confirm that dose rates remain below any values specified in national regulations or guidance and by the operating organization;
(c) Around gauges during maintenance operations, to confirm that the gauge shutter is closed or that the radiation generator is switched off;
(d) At the operators' positions during use of portable gauges, to confirm that radiation levels are acceptable;
(e) At the operators' positions during source loading and unloading operations;
(f) At the entrance to a gauge enclosure, to confirm that the gauge shutter is closed or that the radiation generator has ceased to emit radiation;
(g) Around the transport package before transporting a portable gauge to and from the site, to confirm the presence of the source;
(h) Around vehicles transporting portable gauges before departure to and from the site.

7.3. Measurements of radioactive contamination should not normally be necessary; however, such measurements might be appropriate if there is reason to suspect that a sealed source encapsulation has been damaged or is leaking.

7.4. The workplace monitoring programme should describe the locations to be monitored, the frequency of monitoring and the records to be kept. This information should be included in the local rules and should also be described in the radiation protection programme. Dose rate investigation levels (see para. 4.29) for each measurement location should be prescribed, and the actions to be taken if these values are exceeded should be specified. Records of the workplace monitoring programme are required to be made available to appropriate persons, including workers and the regulatory body (see paras 2.45 and 3.98 of GSR Part 3 [9]).

SELECTION, MAINTENANCE AND CALIBRATION OF WORKPLACE MONITORING INSTRUMENTS

7.5. The operating organization should ensure that a sufficient number of suitable dose rate monitors are made available. While there are many types of monitor for measuring gamma radiation levels, some might not be suitable for accurately measuring low energy photons (e.g. from X ray gauges), which could result in a significant underestimation of the dose rate. Monitors should be calibrated in terms of the radiation fields likely to be encountered in the workplace. Specialized monitoring instruments are necessary for the measurement of beta radiation and for the measurement of neutron radiation. Information and guidance on the suitability of monitors should be obtained from manufacturers and from qualified experts.

7.6. The operating organization should arrange for workplace monitoring instruments to be formally tested or calibrated at periodic intervals by a specialized testing laboratory. A number of operating characteristics of the workplace monitoring instrument should be assessed in these tests or calibrations. These operating characteristics include the response to known dose rates at specific energies, the linearity of the response, and the behaviour of the monitor at low dose rates and at very high dose rates. The frequency and the type of tests or calibration, together with the associated record keeping, should comply with regulatory requirements, or else they should be as recommended in appropriate international standards or guidelines. The recommendations of the manufacturer of the workplace monitoring instruments should also be taken into account.

7.7. The operating organization should prepare a procedure for undertaking routine operational checks of workplace monitoring instruments. These checks might include physical checks (i.e. of whether the instrument is damaged), battery checks and, if applicable, zeroing of the scale. The response of the monitor to radiation should be checked before use. This can be done, for example, by using a low activity test source of which the characteristics are well known, or by placing the monitor close to the surface of a nuclear gauge housing when the source is in its shielded position. The regulatory body may require that such checks be performed in accordance with formal procedures and that the results be recorded.

7.8. Account should also be taken of the environmental conditions in which workplace monitoring instruments are to be used. Some instruments are unsuitable for use in very humid or very hot locations, and some are not robust enough for use on industrial sites. On some sites, special types of workplace monitoring instrument might have to be used. For example, on some petrochemical sites, only monitoring instruments that are designed to minimize the likelihood of accidental ignition of flammable fumes or vapours (‘intrinsically safe monitoring instruments’) are allowed to be used.

7.9. Some workplace monitoring instruments are affected by radiofrequency transmissions. If radiation monitoring is to be conducted close to equipment that generates high levels of radiofrequency radiation, then the use of specially designed radiofrequency shielded instruments should be considered.

7.10. Account should also be taken of noise levels in the workplace. The audible signals from workplace monitoring instruments should be loud enough to be heard and they should be supplemented by vibration or visible signals, as appropriate.

8. CONTROL OF RADIOACTIVE SOURCES

8.1. The Code of Conduct on the Safety and Security of Radioactive Sources [14] applies to all radioactive sources that might pose a significant radiological risk to individuals, society and the environment, and serves as guidance to States on the safety and security of Category 1, 2 and 3 sources.

8.2. Sources used in nuclear gauges are generally considered to be Category 3 or Category 4 sources as defined in RS-G-1.9 [3].

8.3. The operating organization is required to ensure that sources are kept under proper control (see para. 3.55 of GSR Part 3 [9]). This should apply from the time they are first acquired until they are finally returned to their original supplier or are otherwise safely dealt with at the end of their lifetime.

8.4. The operating organization should ensure that it only obtains radioactive sources from authorized suppliers and that disused sources are returned to the original supplier or transferred to another authorized body in accordance with regulatory requirements. The import and export of radioactive sources should be consistent with the recommendations in the Code of Conduct on the Safety and Security of Radioactive Sources [14] and the supplementary guidance on import and export controls [20].

8.5. Paragraph 3.53 of GSR Part 3 [9] states:

> "Registrants and licensees shall maintain an inventory that includes records of:
>
> (a) The location and description of each radiation generator or radioactive source for which they are responsible;
> (b) The activity and form of each radioactive source for which they are responsible."

8.6. As well as maintaining the inventory records described in para. 8.5, the operating organization should conduct periodic accountancy checks of sources, to confirm that they are in their assigned locations and are secure, that any warning signs are visible and that the source details are clearly displayed. National regulations may specify how frequently the accountancy checks need to be conducted, but in general, the following can be applied:

(a) Sources in installed gauges should be accounted for at least once per month.
(b) Sources in portable gauges should be accounted for every day they are out of the store and once a week when they are in storage.

8.7. Sources should only be removed from a source store or moved to another location by trained workers authorized by the operating organization. The workers should log their name, the date and time, and the new location of the source(s). These records should be audited by the radiation protection officer at least once per month, to ensure that all radiation sources are in the correct location. Nuclear gauges that incorporate neutron generators (i.e. containing tritium) should be included in the accountancy procedures for radioactive sources and for radiation generators.

8.8. Each radioactive source container should have a lock (or outer locked container or enclosure) designed to prevent unauthorized or accidental removal of the source. Storage facilities are required to be kept locked when containing radioactive sources except when under the direct surveillance of operating personnel (see para. 3.59 of GSR Part 3 [9]).

8.9. A gauge containing a disused source should not be disposed of as scrap. It should be forwarded to an authorized facility in accordance with regulatory requirements. Until such transfer is effected, the disused source should be included in the source inventory of the facility and subject to accountancy checks as specified in para. 8.6.

8.10. Any suspected loss of control over a radiation source in a nuclear gauge should be promptly investigated by the operating organization; the regulatory body (and any other relevant authority) should be notified, as specified in regulatory requirements and the relevant emergency plans and procedures.

9. NUCLEAR SECURITY CONSIDERATIONS

9.1. The aim of security measures for radioactive sources is to deter, detect, delay and respond to unauthorized access to the sources. Some radioactive sources used in nuclear gauges have been involved in incidents (see Annex III), and it should be assumed that there could be a significant radiological impact if such sources were to be used for malicious purposes.

9.2. The following paragraphs are intended to raise awareness about the security issues that need to be addressed and which are covered in detail in the IAEA Nuclear Security Series publications. In particular, IAEA Nuclear Security Series No. 14 [21] provides recommendations to States and competent authorities on how to develop or enhance, to implement and to maintain a nuclear security regime for radioactive material, associated facilities and associated activities. IAEA Nuclear Security Series No. 11-G (Rev. 1) [22] contains more specific guidance to assist States in the development of regulatory requirements for the security of radioactive sources. IAEA Nuclear Security Series No. 9-G (Rev. 1) [23] provides guidance on security in the transport of radioactive material.

THE INTERFACES BETWEEN SAFETY AND NUCLEAR SECURITY

9.3. Safety measures and security measures have in common the aim of protecting human life and health, society and the environment. Safety measures and security measures should be designed and applied in an integrated manner, and as far as possible in a complementary manner, so that security measures do not compromise safety and safety measures do not compromise security.

9.4. To ensure that safety measures and security measures are applied in a complementary manner, the government may designate a body responsible for managing the interfaces between safety and security in relation to radioactive sources. Alternatively, a single regulatory body may be assigned responsibility for both the safety and the security of radioactive sources under the national regulatory framework.

9.5. In the use of radioactive sources in nuclear gauges, there might be an interface between security measures and safety measures with regard to access to information. For safety purposes, information on the locations and characteristics of radioactive sources and the safety measures in place might need to be readily accessible. However, this information might also be of potential value to an adversary and security considerations may indicate that the confidentiality of some sensitive information needs to be protected. Guidance on the protection and confidentiality of sensitive information is provided in IAEA Nuclear Security Series No. 23-G [24]. An appropriate balance needs to be maintained between the availability of information for safety reasons and the need to protect sensitive information for security reasons.

9.6. The accidental loss of radioactive sources used in nuclear gauges, which might have security as well as safety implications, is addressed through the control measures described in Section 8. The primary security concerns are the possibility of theft and sabotage of radioactive sources. Effective security measures will address these concerns, and will also provide some inherent benefit by contributing to preventing accidental loss of control.

9.7. Safety measures aimed at preventing the loss of radioactive sources, or for general radiation protection purposes, can also provide some benefit against the theft of sources. However, the element of intent involved in theft means that additional security measures might be needed against theft.

9.8. IAEA Nuclear Security Series publications provide guidance on how to define the requirements for the security of radioactive sources using a graded approach, based on considerations of threat, the nature of the sources and the relative attractiveness of the material for use in a malicious act. IAEA Nuclear Security Series No. 11-G (Rev. 1) [22] suggests using the IAEA's categorization system, set out in RS-G-1.9 [3], in order to assign a particular security level to sources and to help define the necessary security measures. Nuclear gauge sources are typically assigned to security level C. The security measures required for each security function (i.e. deterrence, detection, delay, response, security management) for security level C are described in detail in IAEA Nuclear Security Series No. 11-G (Rev. 1) [22].

9.9. Owing to their portability and the fact that they may be used outside of a secure facility, portable gauges might need additional security measures or procedures to ensure that they remain adequately protected and under control during transport, during use and while they are not in use (i.e. in storage). The specific details of such additional measures will depend on the threat assessment. IAEA Nuclear Security Series No. 11-G (Rev. 1) [22] also contains illustrative security measures, including those for mobile operation where measures applicable to a fixed installation are not practicable.

10. SAFE HANDLING OF RADIOACTIVE SOURCES AND RADIATION GENERATORS

GENERAL

10.1. The responsibilities of manufacturers and suppliers of radiation generators and radioactive sources, such as those used in nuclear gauges, are established in Requirement 17 of GSR Part 3 [9].

10.2. A wide range of radiation sources are used in nuclear gauges, including radioactive sources (emitting beta, gamma or neutron radiation), and X ray and neutron generators. Details are provided in Annexes I and II. The source, nuclear gauge and ancillary equipment should all be obtained from an authorized manufacturer or supplier with an established quality management system such as ISO 9001 [25] or the system described in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [26] or an equivalent national standard, to ensure that the design safety features are reproduced consistently.

10.3. Nuclear gauges typically consist of several subcomponents that make up a gauging system or installation. The design and operation of these various components are interrelated. Safety should not be compromised by using components that do not meet the original design specifications.

10.4. Manufacturers and suppliers of radioactive sources and radiation generators are required to ensure that information on the safe use of the equipment is made available to operating organizations. This information is required to be made available in an appropriate language understandable to users (para. 3.49(c) of GSR Part 3 [9]).

10.5. The operating organization should ensure that nuclear gauges and ancillary equipment are not modified without prior assessment of the implications of the modification for protection and safety. The safety assessment should be reviewed by a qualified expert or by the supplier, and it should be verified that the equipment meets the requirements of the regulatory body. It should also be determined whether additional authorization or approval is required.

10.6. Permanently installed nuclear gauges should meet the requirements of IEC 62598 [12]. In cases where these requirements are not met (e.g. owing to a special design or unusual application), the operating organization should ensure that the gauge is not used until (a) a safety assessment has been performed by a qualified expert to determine whether any additional safety measures should be implemented and (b) regulatory clearance is obtained for the use of such a gauge.

10.7. The main practical elements that can be used to ensure the restriction of radiation exposures are: time, distance, shielding and prevention of access to the radiation beam. Workers should be instructed not to linger in areas where there are high radiation levels, and any work to be undertaken close to a source should be planned so as to be done in the shortest practicable time. Distance from a source of radiation should be increased to the extent possible to reduce the dose rate. A nuclear gauge that meets regulatory requirements will incorporate adequate shielding. The amount of shielding required will be determined by the type and energy of the radiation and the activity of the source. For example, several centimetres of lead could be required around a gamma source in a vessel level gauge, or a few millimetres of aluminium around a beta source in a thickness gauge. The environment in which the gauge will be used should also be considered when deciding on the shielding materials specified in the design (e.g. high temperature or corrosive chemicals could significantly affect some types of shielding).

10.8. Nuclear gauges operate by producing a beam of radiation. It is, therefore, necessary to prevent access to this beam, for example by using shutters (manual or automatic), mechanical guarding and/or interlock systems. In some cases the designation of controlled areas might be necessary, for example during maintenance operations, in order to prevent access by unauthorized persons.

10.9. In terms of the design of portable gauges, heavy shielding is often impractical, and it is not always possible to utilize interlocked shutters to shield the beam. Therefore, care should be taken to ensure that persons are not exposed to the primary beam. Prevention of access by using physical barriers is not always practicable, and other means should be used, for example by ensuring that the controlled area is under continuous surveillance (e.g. by the gauge operator) and/or by using portable barriers and suitable warning notices.

SEALED RADIOACTIVE SOURCES

10.10. Beta, gamma and neutron source nuclear gauges contain a sealed radioactive source housed in a shielded container. The source normally remains in the shielded container and is exposed by opening a shielded shutter. Radioactive sources used in nuclear gauges are normally contained within a sealed source capsule. These source capsules should be compatible with the gauge and any relevant ancillary equipment with which they are used, and they should also meet international or equivalent national standards, for example:

(a) Source capsules should be designed, manufactured and tested to ensure that they meet the relevant requirements set out in ISO 2919 [11] or an equivalent national standard.
(b) In the case of gamma and neutron sources, source capsules should be certified as meeting the requirements for special form radioactive material as established in IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition [27].
(c) Source capsules should be leak tested in accordance with the requirements set out in ISO 9978 [28] or an equivalent national standard, and there should be a valid leak test certificate that is traceable to each individual source (see also para. 10.31).
(d) Source capsules should be marked in accordance with the requirements of ISO 2919 [11] or an equivalent national standard. At a minimum, sources should be marked with the radiation symbol (trefoil) [18] and the word “RADIOACTIVE”. They should also be durably marked with the manufacturer’s serial number.

10.11. Some manufacturers specify a recommended working life for a sealed radioactive source. The recommended working life is based on a number of factors, including the half-life of the source, the construction of the source and the impact of the environment in which the source is used. The recommended working life is an indication of the period of time over which the source is expected to retain its integrity.

10.12. Manufacturers usually recommend that a source be replaced when it reaches the end of its recommended working life. The regulatory body, however, may agree to the extended use of a source beyond its recommended working life if the source is subjected to more frequent wipe tests or more detailed leakage tests as specified in ISO 9978 [28]. Alternatively, a physical assessment of the condition of the source by a suitably qualified body or expert may be performed to advise about its continued use.

10.13. The special form source certificate should be revised and updated at least every five years or as required by national regulations (e.g. see Refs [13, 29]). Updated special form certificates are normally issued by the source manufacturer; however, it is the responsibility of the operating organization (as consignor) to ensure that there is a valid special form certificate for all radioactive sources that are to be transported, in accordance with the requirements of SSR-6 (Rev. 1) [27].

MARKING AND LABELLING OF NUCLEAR GAUGES CONTAINING RADIOACTIVE SOURCES

10.14. Each radioactive source container or gauge assembly should be permanently and clearly marked with the following details:

(a) The international ionizing radiation symbol (trefoil) [18];
(b) The word “RADIOACTIVE” in letters not less than 10 mm in height, together with a brief warning in a language appropriate to the country or region of use;
(c) The chemical symbol(s) and mass number of the radionuclide(s) for which the device is suitable (e.g. ^{137}Cs or ^{241}Am);
(d) The activity of the source(s) on a stated date;
(e) The make, model and serial number of the device;
(f) The name of the manufacturer and/or distributor of the source.

10.15. For portable gauges, the package used during transport should display a durable fireproof label bearing information about the radioactive source that it contains, including the following:

(a) The chemical symbol and mass number of the radionuclide(s);
(b) The activity of the source(s) on a stated date;
(c) The identification number of the sealed source(s);
(d) The name of the manufacturer.

NEUTRON RADIATION GENERATORS USED IN INSTALLED NUCLEAR GAUGES

10.16. A neutron generator is a compact linear accelerator of deuterium nuclei, which produces 14 MeV neutrons. Its components include the accelerator tube (neutron tube), a target normally containing tritium, a high voltage power supply and a measurement module.

10.17. Neutron generators are used for determining the concentration of a number of elements that can be excited through different neutron techniques (inelastic scattering, thermal capture, neutron activation). This technique is used in the coal industry and the cement industry.

10.18. Shielding materials of low atomic number are normally the most cost effective and practical approach for reducing the dose rates around neutron generators. An example shielding calculation for neutron generators is provided in IAEA Safety Standards Series No. SSG-57, Radiation Safety in Well Logging [6]. The geometry of the shielding should be designed to restrict the exposure of the workers undertaking the calibrations due to scattered neutron radiation. The maximum dose rate on the exterior of the shielded neutron generator should be within the limits stipulated by the regulatory body.

10.19. Gamma radiation is emitted both during neutron generation (from inelastic interaction of high energy neutrons) and for some time after the generator is turned off (from capture of thermal neutrons and the subsequent radioactive decay of neutron activation products). If significant dose rates remain after the generator is switched off, a holding time to allow for the decay of activation products will be necessary.

10.20. In some cases, neutron generators can accumulate radioactive contamination due to neutron activation of loose material on the outer surfaces of the neutron tube. In such cases, appropriate personal protective equipment should be worn by workers when handling the generator. Checks for contamination should be conducted periodically (at least once a year), upon receiving and shipping out the neutron generator, and before the repair of the neutron generator.

X RAY GENERATORS USED IN INSTALLED NUCLEAR GAUGES

10.21. An advantage of nuclear gauges using X ray generators is that when they are switched off the emission of radiation ceases immediately. However, in many nuclear gauges, the X ray generator normally remains on and the X ray beam is controlled by a shutter. This shutter should be interlocked, so that any attempt to access the X ray beam (e.g. by opening an access door) will cause the X ray tube to automatically and immediately switch off. The shutter should be fitted with safety features such that it cannot be unintentionally opened.

10.22. The maximum dose rate in accessible locations close to the tube housing when the shutter is closed should be within the limits specified by the regulatory body.

10.23. The gauge should be fitted with an illuminated warning sign that is activated when the X ray equipment is energized. The status of the shutter (i.e. open or closed) should also be indicated by an illuminated sign. These signs should be legible and readily discernible from all accessible sides of the X ray equipment.

10.24. Under normal operating conditions it should not be possible for workers operating X ray equipment to expose any part of the body to the primary X ray beam. If it is suspected that such an exposure has occurred, appropriate emergency response action (see Section 13) should be initiated immediately. Attention should also be paid to any scattered radiation.

10.25. Special maintenance procedures, such as beam alignments or other adjustments, should not be performed unless measures designed to prevent exposure of the eye or other parts of the body to the primary beam have been implemented. If it is necessary to operate the X ray equipment with a safety interlock deactivated, this procedure should be approved by the regulatory body. All such special procedures should be undertaken by persons with appropriate training and under the supervision of a radiation protection officer. In addition, the number of persons working with the X ray equipment while it is energized should be the minimum necessary to perform the procedure safely. During such procedures, when the X ray equipment is energized, access of non-essential personnel to the location of the X ray equipment should be prevented by physical barriers. A sign warning of the operations in progress should be placed at the access points to the area.

SOURCE CHANGERS AND SHIPPING CONTAINERS

10.26. Source changers should be used for the safe exchange of old and new radioactive sources. Normally, these are shipping containers used by the source supplier or gauge maintenance company to send a new source to the operator, facilitate the exchange and return the old source to the supplier or another authorized organization. When they are not in use, sealed sources should be safely stored in storage containers and unauthorized access to the source containers should be prevented. When source changers are used as transport containers, the consignor should ensure that source changers are transported in compliance with the requirements of SSR-6 (Rev. 1) [27].

10.27. Containers used for storing or exchanging radioactive sources from nuclear gauges should be designed to meet the applicable national safety standards. Such containers should include a lock or should have an outer locked container designed to prevent unauthorized or accidental removal of the sealed source from its shielded position. Storage containers and source changers should be kept locked (with the key removed at all times) when they contain sealed sources, unless they are under the direct surveillance of an authorized worker.

STORAGE OF RADIOACTIVE SOURCES FROM NUCLEAR GAUGES

10.28. There will be occasions when radioactive sources used in nuclear gauges need to be stored. Examples include: portable gauges not in use; gauges removed from a production line during maintenance; new gauges awaiting installation and old gauges awaiting disposal.

10.29. To ensure the safety and security of the radioactive sources the storage facility should:

(a) Provide adequate shielding.
(b) Be physically secure (e.g. locked when not in use).
(c) Be a dedicated enclosure that is used exclusively for storage of nuclear gauges and associated radioactive sources, and is not used as a general storage area for other goods.
(d) Be fireproof and not contain other hazardous materials (e.g. flammable, explosive, toxic or corrosive substances). Such hazardous material should not be stored near the storage facility for radioactive sources.
(e) Be protected from environmental conditions that might adversely affect the integrity of the gauges.
(f) Be appropriately labelled (e.g. with the radiation symbol [18] and warning notices in the local language).

MAINTENANCE OF NUCLEAR GAUGES

10.30. Some nuclear gauges are installed or used in locations where environmental conditions can result in the protection and safety of the gauge being adversely affected; for example, shielding might be degraded, shutters might become stuck or warning notices might become illegible. Nuclear gauges should be subject to a routine preventive maintenance schedule. Persons performing the maintenance work should be made aware of the radiation hazards and should be appropriately trained. When working close to a nuclear gauge, a radiation monitor should always be used to confirm that any shutters are fully closed and that the source is adequately shielded.

LEAK TESTING OF RADIOACTIVE SOURCES IN NUCLEAR GAUGES

10.31. When a new radioactive source is purchased it should be supplied with a certificate confirming that there is no leakage of radioactive material. Periodic tests should be performed in accordance with the procedure specified in ISO 9978 [28] by an appropriately trained and qualified person to ensure that the structure of the source remains intact. The intervals for leak testing should not normally exceed two years, and will normally be specified by the regulatory body. Radioactive sources in gauges that are used under harsh industrial conditions (e.g. high temperature, corrosive chemicals, high levels of vibration) might need to be tested more frequently.

CESSATION OF USE AND REMOVAL OF NUCLEAR GAUGES

10.32. As stated in para. 3.60 of GSR Part 3 [9], the operating organization: "shall ensure that arrangements are made promptly for the safe management of and control over radiation generators and radioactive sources, including appropriate financial provision, once it has been decided to take them out of use."

10.33. When a nuclear gauge is no longer used, and there are no plans to use it again in the foreseeable future, the gauge should be formally taken out of use and arrangements made for it to be removed from the site. All disused radiation sources should be managed in a manner that is consistent with the national regulatory framework and, if necessary, is subject to approval by the regulatory body. This should include the following:

(a) Radioactive sources (including calibration sources, as applicable) and radiation generators should, subject to approval by the regulatory body, be transferred to an authorized organization for safe disposal. If possible, the operating organization should return the source or generator to the original supplier; alternatively, the operating organization may take another action as authorized by the regulatory body. Comprehensive records should be kept by the operating organization of all authorizations for the storage, transfer or disposal of radioactive sources (including any certificates provided by recipients or by disposal facilities for radioactive waste). The relevant records should be maintained as specified by the regulatory body.
(b) The operating organization should return disused neutron generators to the original supplier. Otherwise, the generator should be made inoperable and,

subject to approval by the regulatory body, transferred to an authorized organization for safe disposal (i.e. of the tritium source).

(c) In cases where all radiation sources are to be removed from the facility, all radiation symbols (trefoils) and other relevant notices should be removed from the facility and a workplace monitoring survey (see Section 7) should be conducted by the radiation protection officer or a qualified expert to provide additional confirmation that the radioactive sources have been removed from the site. A final decommissioning plan should be prepared in advance, which includes the final radiation survey and details of the storage, transfer or disposal of sources of radiation. The final decommissioning plan is required to be submitted to the regulatory body for review and approval (see Requirement 11 of IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [30]). Further recommendations are provided in IAEA Safety Standards Series No. SSG-49, Decommissioning of Medical, Industrial and Research Facilities [31].
(d) The operating organization should inform the relevant authorities when all sources of radiation have been removed from the site.
(e) Radioactive waste should be managed in accordance with recommendations provided in IAEA Safety Standards Series No. SSG-45, Predisposal Management of Radioactive Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education [32] or an equivalent national standard, and in accordance with regulatory requirements.
(f) An option for disposal of sealed sources in nuclear gauges is borehole disposal. Recommendations on borehole disposal facilities are provided in IAEA Safety Standards Series No. SSG-1, Borehole Disposal Facilities for Radioactive Waste [33]. A technical manual on borehole disposal of disused sealed sources is provided in Ref. [34].

10.34. In the case of old nuclear gauge systems, it is possible that the manufacturer and/or original supplier is no longer in business. If this is the case, decommissioning and disposal of the old sources should be arranged in accordance with the requirements specified by the regulatory body.

10.35. During decommissioning (or even during the operation of the nuclear gauge facility), if the operating organization discovers a source in its possession for which there are no records to confirm that it is subject to an authorization issued by the regulatory body, such a source should be deemed to be out of regulatory control. If this is the case, the operating organization should check that the situation is safe (i.e. following its own emergency plan; see Section 13) and notify the regulatory body. Guidance on a national strategy for managing such sources is provided in IAEA Safety Standards Series No. SSG-19, National

Strategy for Regaining Control Over Orphan Sources and Improving Control Over Vulnerable Sources [35].

11. USE OF PORTABLE NUCLEAR GAUGES

PREPARATION FOR WORK ON OTHER SITES

11.1. Where a portable nuclear gauge is to be used on the premises of a client rather than on the premises of the operating organization, the client should be consulted on the preparation and planning of the work. This should include agreeing the location and time for the work with the gauge to be performed. Any specific measures for protection and safety of persons on the site should be discussed between the parties, to avoid possible confusion on the site, while remaining consistent with regulatory requirements.

11.2. The gauge users should be made aware of any hazards on the site where the work is planned. Any permit-to-work systems or other site safety procedures implemented by the client should be followed. The client should be provided with a copy of the operating organization's local rules and emergency plans and procedures.

11.3. The operating organization and the client should agree on the planned timescale of the work and the duration of the period over which nuclear gauge work will be performed. The client should allow sufficient time for the nuclear gauge work to be performed safely.

11.4. The operating organization should inform the client about the radiation source(s) that it is planning to use on the site and the associated hazard. It should ensure that proper storage facilities are arranged in advance for any nuclear gauges that it intends to store on the site overnight (this might require separate authorization by the regulatory body). (See also paras 11.12–11.15).

11.5. Work should only be performed on-site when the gauge and any necessary items of ancillary equipment are in good working order. If any faults are found, the equipment should not be used until a suitable replacement is provided or a repair is made.

DESIGNATION OF CONTROLLED AREAS AND SUPERVISED AREAS ON THE SITE

11.6. Work with mobile nuclear gauges should be performed in an area designated as either a controlled area or a supervised area, based on the criteria described in Section 4. Normally other workers should be excluded from this area.

11.7. The regulatory body may specify the maximum permitted dose rate around the area where mobile nuclear gauges are used, typical values being in the range 2.5–20 μSv/h. It is often practicable to achieve a dose rate at the boundary that is below 1 μSv/h.

Warning notices

11.8. Notices should be displayed at suitable positions on the boundary of the controlled area, as appropriate. The notices should bear the radiation symbol [18], warnings and appropriate instructions in a language understood by persons working on the site.

Supervising and monitoring the area

11.9. The immediate area around a portable nuclear gauge (controlled area) should be cleared of all persons except for the gauge operator. Before using the gauge, the operator should confirm that there are no unauthorized persons within the immediate area.

11.10. Dose rates should be measured around the gauge during a test exposure (or during the first exposure, depending on the circumstances) to confirm that it is correctly designated and that any barriers are correctly positioned.

TRAINING OF USERS OF PORTABLE GAUGES

11.11. The workers operating portable nuclear gauges should be suitably trained and be familiar with the equipment, its modes of operation and its potential problems. The workers should also have an understanding of the radiation source, its radiation safety aspects, the manner in which it is operated, and the necessary precautions during any source handling or gauge maintenance procedures such as shutter cleaning.

TEMPORARY STORAGE OF PORTABLE NUCLEAR GAUGES

11.12. Portable nuclear gauges containing radioactive sources might, if necessary, be stored on the site overnight or between operations. The need for such storage should be identified in the planning phase, and arrangements should be made with the client for the provision of suitable storage facilities that comply with regulatory requirements.

11.13. On-site storage facilities should consist of a lockable room, purpose-built store or storage pit to which access is controlled. On-site storage facilities should provide the same level of protection and safety and security as storage facilities at the operating organization's main base. A suitable storage facility should provide protection from the prevailing environmental conditions and should also provide an adequate level of safety and security. The storage facility should be weatherproof and resistant to fire. The storage facility should be located at a remote distance from any other hazardous materials such as explosives.

11.14. The storage facility should be built of materials that provide sufficient shielding (if needed) to reduce dose rates outside the storage facility to levels specified by the regulatory body. The storage facility should be designated as a controlled area or supervised area, as appropriate.

11.15. The door to the storage facility should be kept locked and the keys should be held only by authorized personnel. Keys should be of specific design that cannot be easily reproduced. A warning notice incorporating the radiation symbol [18] and emergency contact number should be displayed on the door. It is good practice to have two separate locks with different keys on the door to the storage facility, with the two keys being kept by two different persons.

COMPLETION OF WORK AND REMOVAL OF SOURCES FROM THE SITE

11.16. On completion of the work with portable nuclear gauges, workers should use a workplace monitoring instrument to confirm that each gauge can be safely transported from the site.

11.17. Before leaving the site, the workers should conduct a visual examination to ensure that equipment has not been damaged. Portable gauges should be made ready for transport by placing them in the proper transport containers (see

Section 12). The container should be securely stowed in the vehicle to avoid damage during transport.

12. TRANSPORT OF RADIOACTIVE SOURCES

12.1. Nuclear gauges containing radioactive sources will need to be transported:

(a) From the gauge supplier to the operating organization’s facility;
(b) From the operating organization’s facility to the authorized site of operation in the case of portable gauges;
(c) From the operating organization’s facility to the supplier or other suitably authorized facility at the end of the useful life of the source, if it has become disused for some other reason, or following an accident involving the source.

Radioactive sources used in nuclear gauges might also need to be moved within the operating organization’s facility, for example from the storage room to the location at which it is to be installed.

12.2. The transport of radioactive sources used in nuclear gauges should conform to national regulations and the requirements of SSR-6 (Rev. 1) [27].

12.3. Where applicable, consideration should also be given to binding international instruments for specific modes of transport, such as the Technical Instructions for the Safe Transport of Dangerous Goods by Air of the International Civil Aviation Organization [36], and the International Maritime Dangerous Goods Code of the International Maritime Organization [37]. Regional agreements such as the European Agreement Concerning the International Carriage of Dangerous Goods by Road [38], the Agreement of Partial Reach to Facilitate the Transport of Dangerous Goods signed by the Governments of Argentina, Brazil, Paraguay and Uruguay [39], and the European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways [40], as appropriate, may also apply.

MOVEMENT OF PORTABLE GAUGES WITHIN THE SITE

12.4. When portable nuclear gauges are to be moved within a site, they should be kept in the storage facility until they are to be moved to the new location.

12.5. The gauge should be moved only in the container provided by the manufacturer, and this should be locked and the keys should be removed. The container should be kept under surveillance for the duration of the movement on the site. The keys of the container should be kept by the authorized gauge operator.

TRANSPORT TO ANOTHER SITE

12.6. When a portable nuclear gauge (or portable source from an installed gauge) is to be transported to another site, it should be kept in the storage facility until it is to be moved.

12.7. The gauge (or portable source) should be transported only in the container provided by the manufacturer for transport purposes, and this should be locked and the keys should be removed.

12.8. SSR-6 (Rev. 1) [27] assigns responsibilities for the transport of radioactive material to the following:

(a) The consignor (the person or organization that prepares a consignment for transport);
(b) The carrier (the person or organization that undertakes transport of radioactive material);
(c) The consignee (the person or organization that receives a consignment).

In the case of portable nuclear gauges, the operating organization usually performs all three functions and is required to discharge the responsibilities associated with each function.

12.9. The transport of radioactive material is a complex activity, and a comprehensive overview of the requirements of SSR-6 (Rev. 1) is outside the scope of this Safety Guide. Guidance on how to meet these requirements is provided in IAEA Safety Standards Series No. SSG-26 (Rev. 1), Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2018 Edition) [41].

12.10. Comprehensive guidance on nuclear security in the transport of radioactive material is provided in IAEA Nuclear Security Series No. 9-G (Rev. 1) [23].

13. EMERGENCY PREPAREDNESS AND RESPONSE

GENERAL

13.1. The requirements for an adequate level of preparedness and response for a nuclear or radiological emergency are established in IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [42]. An emergency is:

> "A non-routine situation or *event* that necessitates prompt action, primarily to mitigate a *hazard* or adverse consequences for human life, health, property and the *environment*.
>
> ⓘ This includes *nuclear and radiological emergencies* and conventional *emergencies* such as fires, *releases* of hazardous chemicals, storms or earthquakes.
>
> ⓘ This includes situations for which prompt action is warranted to mitigate the effects of a perceived *hazard*" [8].

13.2. A nuclear or radiological emergency is:

> "An *emergency* in which there is, or is perceived to be, a *hazard* due to:
>
> (a) The energy resulting from a nuclear chain reaction or from the decay of the products of a chain reaction; or
> (b) *Radiation exposure*" [8].

13.3. Incidents involving nuclear gauges have occurred as a result of operator error or equipment failure; some examples are provided in Annex III. Incidents involving nuclear gauges have included the following:

— Jammed or broken shutters;
— Other mechanical damage to gauges (e.g. crushing);
— Abnormal (i.e. higher than expected) dose rates;
— Missing sources;
— Leaking sources due to mechanical impact, fire or corrosion;
— Malevolent actions such as theft of nuclear gauges (especially portable gauges).

13.4. In many cases, incidents involving nuclear gauges can be prevented or their consequences can be mitigated if the following precautions are taken:

(a) Nuclear gauges and associated equipment should meet current regulatory standards.
(b) Workers:
    (i) Should be properly trained and qualified, and they should be competent;
    (ii) Should follow the local rules and other relevant procedures;
    (iii) Should use calibrated workplace monitoring instruments and, if appropriate, wear suitable personal dosimeters before, during and after every source use, and in accordance with the radiation protection programme (see Section 4);
    (iv) Should undertake regular and appropriate inspections of equipment before use;
    (v) Should make proper use of emergency equipment.

DEVELOPMENT OF EMERGENCY PLANS AND PROCEDURES

13.5. Although the prevention of incidents is the first priority, events could still occur that would necessitate protective actions or other response actions. The operating organization is required to have an emergency plan and procedures prepared in advance for the goals of emergency response to be achieved and for the emergency response to be effective (see Requirement 23 of GSR Part 7 [42]).

13.6. The hazards associated with sources used in nuclear gauges and the potential consequences of an emergency need to be assessed to provide a basis for establishing arrangements for emergency preparedness and response, in accordance with Requirement 4 of GSR Part 7 [42]. Potential emergencies that could affect workers, members of the public or the environment should be identified in the operating organization's hazard assessment.

13.7. Emergency preparedness category IV, as described in Table 1 of GSR Part 7 [42], generally applies to nuclear gauges containing radioactive sources. Appropriate emergency arrangements (including plans, procedures, equipment, training, drills, exercises and a quality management programme) that correspond to this category are required to be established. Further recommendations are provided in IAEA Safety Standards Series Nos GS-G-2.1, Arrangements for Preparedness for a Nuclear or Radiological Emergency [43], and GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [44].

13.8. The emergency plans for nuclear gauges should address scenarios such as a missing or lost source, the theft of a source, damage to a gauge producing increased dose rates, damage to a source leading to contamination and failure of a safety system leading to the exposure of persons. Emergency procedures should include the following:

— A clear statement of roles and responsibilities;
— A concept of operations;
— Communication and coordination arrangements;
— Protocols for notification of an emergency;
— Instructions to site personnel;
— Instructions for delineation of the affected area and access control;
— Measures to protect emergency workers.

A qualified expert should be consulted, where possible, when drawing up emergency plans and procedures.

13.9. Recommendations on developing adequate emergency arrangements at the organizational, local and national levels on a step by step basis including templates for emergency plans are provided in GS-G-2.1 [43]. Further practical guidance regarding generic procedures for assessment and response during a radiological emergency is provided in Ref. [45]. Action guides for dealing with radiological emergencies are provided in Ref. [46].

13.10. Emergency arrangements can be regarded as comprising several tasks, each of which should be addressed by the operating organization and relevant response organizations, in accordance with the recommendations provided in GS-G-2.1 [43] for facilities and activities in emergency preparedness category IV.

13.11. Implementation of the on-site emergency plans and procedures may require off-site support (e.g. off-site response organization, emergency services, radiation protection specialists, law enforcement authorities in the event of theft of source) as addressed in GSR Part 7 [42] and GS-G-2.1 [43]. The on-site emergency plan should provide details of any off-site support, and it should be ensured that responders are fully aware of and accept their responsibilities. In particular, the on-site emergency plan should specify the arrangements for immediate and efficient communication between all the parties involved.

13.12. The operating organization is required to submit its emergency plan to the regulatory body for approval, when applying for an authorization (para. 6.19 of GSR Part 7 [42]). The operating organization should also make the emergency plan and associated procedures available to the appropriate off-site authorities.

EMERGENCY EQUIPMENT

13.13. The operating organization is required to ensure that all necessary tools, instruments, supplies, equipment, communication systems, facilities and documentation for responding to emergencies are made available and are under the control of a quality management programme that includes inventory control, testing and calibration (see para. 6.34 of GSR Part 7 [42]).

13.14. For emergencies involving nuclear gauges, consideration should be given to the need for the following equipment, as appropriate:

(a) Appropriate workplace monitoring instruments to measure both high and low dose rates;
(b) Active personal dosimeters;
(c) Barrier materials and warning notices for the temporary designation of a controlled area;
(d) If appropriate, suitable local shielding, such as blanking plates to shield the primary beam in the event of the shutter being stuck in the open position;
(e) Forceps or remote handling tongs, and a spare source container with adequate shielding;
(f) Wipe test kit for leak testing sources and for other surface contamination checks;
(g) Communication equipment (e.g. portable phones);
(h) Spare batteries and torches.

13.15. If it is suspected that a sealed source capsule might have been damaged, extra care should be taken, as radioactive material could leak out of the source and there could be a risk of contaminating people and objects in the vicinity. The detection and measurement of radioactive contamination from the leaking source involve specialized monitoring equipment and expertise. If it is known or suspected that a source capsule has ruptured, the operating organization should promptly seek advice and assistance from a qualified expert. Adequate consideration should be given to the decontamination of persons and equipment, as appropriate, in such instances. Furthermore, the operating organization might seek assistance from the manufacturer or supplier.

EXAMPLE RESPONSE PROCEDURES FOR INCIDENTS INVOLVING NUCLEAR GAUGES

13.16. Paragraphs 13.17–13.20 provide practical guidance on the immediate actions to be taken by workers and by the radiation protection officer when an incident involving a nuclear gauge occurs. Although the actions are listed in the sequence in which they can be expected to be performed, it might be necessary to implement the actions in a different sequence depending on the actual circumstances of the incident. The operating organization should develop emergency procedures taking account of the recommendations provided in this section and the postulated accident scenarios based on the hazard assessment. As with any radiological emergency, the first priority of the emergency response should be the protection of persons.

Actions to be taken for events involving nuclear gauges containing radioactive sources

13.17. In the case of an event involving a nuclear gauge containing a radioactive source, workers should undertake the following actions:

(a) Quickly recognize an abnormal situation that might constitute an emergency and implement the appropriate emergency procedures;
(b) Remain calm and move away from the gauge and ensure that any other workers in the vicinity are evacuated and informed that there might be an emergency;
(c) Inform the radiation protection officer of the operating organization;
(d) Measure the dose rates and record any doses measured by active personal dosimeters, if these have been worn;
(e) Confirm, establish or re-establish controlled area barriers on the basis of dose rate reference levels consistent with regulatory requirements and the emergency plan and procedures;
(f) Prevent access to the controlled area;
(g) Use necessary personal protective equipment;
(h) Maintain surveillance of the controlled area;
(i) Inform the relevant authorities (and the client, if the emergency occurs at the client's site) and seek assistance as prescribed in the emergency plan and procedures.

13.18. In the case of an event involving a nuclear gauge containing a radioactive source, the radiation protection officer should undertake the following actions:

(a) Implement a specific course of action on the basis of previously established emergency plans and procedures, taking care to minimize doses that might be received as a result of this course of action.
(b) Move to a location away from the controlled area and rehearse the planned course of action before entering the controlled area to implement the emergency plan.
(c) Implement the planned course of action to the extent that training, equipment, the actual situation and authorizations allow; under no circumstances should the source come into contact with the hands or other parts of the body.
(d) If the course of action taken is unsuccessful, leave the controlled area and consider the next course of action while maintaining surveillance of the controlled area.
(e) Call for technical assistance, if necessary, from a qualified expert or from the manufacturer of the source and/or the gauging equipment, as appropriate. Such assistance may form part of the emergency plan and procedures, in which case it should be planned and agreed upon between the various parties in advance.
(f) When the situation is brought under control and the source is safe, investigate the incident and estimate any doses received.
(g) If personal dosimeters were worn, return these to the dosimetry service for rapid assessment.
(h) Arrange for any damaged or malfunctioning equipment to be repaired by the manufacturer or a qualified expert before any reuse.
(i) Prepare a report and notify the regulatory body, in accordance with regulatory requirements.

Actions to be taken for events involving nuclear gauges containing radiation generators

13.19. In the case of an event involving a nuclear gauge containing a radiation generator, workers should undertake the following actions:

(a) Quickly recognize an abnormal situation that might constitute an emergency;
(b) Turn off the electrical power to the generator;
(c) Inform the radiation protection officer of what has happened;
(d) Perform a radiation survey to determine whether there is any residual radiation hazard;

(e) Not move any equipment until details such as position, beam direction and exposure settings (tube voltage, current and time) have been recorded;
(f) Not use the gauge until it has been examined and repaired by the manufacturer or by a qualified expert.

13.20. In the case of an event involving a nuclear gauge containing a radiation generator, the radiation protection officer should undertake the following actions:

(a) Estimate the doses that could have been received;
(b) If personal dosimeters were worn, return these to the dosimetry service for rapid assessment;
(c) Prepare a report and notify the regulatory body, in accordance with regulatory requirements.

TRAINING AND EXERCISES

13.21. In accordance with para. 5.44 of GSR Part 7 [42], all personnel who will participate in implementing the emergency response actions are required to be adequately qualified and trained for the effective fulfilment of their roles. This should include familiarization with and understanding of the emergency plan, together with specific training on the application of emergency procedures and on the use of emergency equipment. This is also required to include guidance and training on the approximate radius of any inner cordoned off area in which urgent protective actions would initially be taken and on the adjustment of this area on the basis of observed or assessed conditions on the site.

13.22. Individual workers should implement only those parts of the emergency plan for which they have been authorized and trained and for which they have the appropriate equipment. Provisions for training should be reviewed periodically to ensure the continued proficiency of workers.

13.23. Emergency exercises should be held to test critical components of the emergency plan, at intervals that are commensurate with the potential hazard. Small scale exercises should be held frequently to ensure that the contact details of persons and organizations with responsibilities in the emergency response are up to date.

13.24. Any lessons identified from exercises are required to be fed back into reviews and, as necessary, revisions of the emergency plans and procedures (see para. 6.36 of GSR Part 7 [42]).

PERIODIC REVIEWS OF THE EMERGENCY PLAN

13.25. Formal reviews of the emergency plan should be undertaken periodically. Such reviews should include provisions to update the emergency plan in response to lessons from exercises or from emergencies.

REPORTING

13.26. The primary objective of emergency preparedness and response is to mitigate the consequences of emergencies. To achieve this, incidents that have occurred should be critically reviewed so that the lessons identified can be used to provide feedback for improving equipment, maintenance procedures, operating procedures and emergency arrangements. A comprehensive report that includes an analysis of the emergency and the emergency response should be prepared.

13.27. The report on an incident involving nuclear gauges should be prepared by the radiation protection officer with the assistance of qualified experts if necessary. Such reports should be submitted to senior management, the regulatory body and other relevant authorities at local, regional or national level. If the incident could have been caused by an equipment malfunction, the supplier and the regulatory body should be notified so that the equipment can be evaluated and appropriate action taken.

13.28. The report on an emergency should include the following:

(a) A description of the emergency, with as much detail as possible of the equipment involved. The details should include model numbers and serial numbers wherever possible.
(b) Environmental conditions at the time of the emergency, with particular reference to whether or not these conditions played any significant part in causing the emergency or affecting the outcome.
(c) The specific cause(s) of the emergency.
(d) Details of actions taken to regain control of the situation and to restore conditions to normal, with special reference to any actions that were notably beneficial or detrimental.
(e) The personnel involved and their duties, tasks and qualifications.
(f) An assessment and summary of the doses received by all affected individuals.
(g) Corrective actions recommended with the aim of preventing similar emergencies in the future.
(h) Lessons from managing the emergency.

COMMUNICATION WITH THE PUBLIC

13.29. Communication with the public on emergencies involving nuclear gauges (for example, in the event of a gauge being lost or stolen) should be conducted by the appropriate department of the operating organization in discussion with the regulatory body and other relevant authorities as specified in the emergency plan and procedures. Requirements 10 and 13 of GSR Part 7 [42] address arrangements for communication with the public; further recommendations on keeping the public informed are provided in GS-G-2.1 [43].

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Annex I

OVERVIEW OF NUCLEAR GAUGES

I–1. Nuclear gauges incorporate a radioactive source or a radiation generator. Table I–1 presents examples of nuclear gauges used for various applications, including typical sources, their activities and the corresponding D values in accordance with IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [I–1], and Table I–2 provides examples of nuclear gauge systems used in manufacturing industries.

TABLE I–1. NUCLEAR GAUGES: APPLICATIONS, RADIATION SOURCES AND D VALUES

Type	Application	Typical radiation source(s)	D values (TBq) [I–1]
Level gauges	Portable gamma level indicator	^{137}Cs or ^{60}Co (7–20 MBq)	0.1 (^{137}Cs); 0.03 (^{60}Co)
	Installed gamma level indicator	^{137}Cs or ^{60}Co (1–2 GBq), X ray generators	0.1 (^{137}Cs); 0.03 (^{60}Co)
	Relay gamma level gauge	^{137}Cs or ^{60}Co (1–2 GBq)	0.1 (^{137}Cs); 0.03 (^{60}Co)
	Gamma transmission level gauge	^{137}Cs (1–2 GBq)	0.1
	Neutron backscatter gauge for level and interface detection	$^{241}Am/Be$ (10–37 GBq) or ^{252}Cf (10–20 GBq)	0.06 (^{241}Am); 0.02 (^{252}Cf)
Density, concentration and thickness measurement gauges	On-line liquid density gauge	^{241}Am (up to 4 GBq)	0.06
	Gamma high performance density gauge	^{137}Cs or ^{60}Co (750 MBq)	0.1 (^{137}Cs); 0.03 (^{60}Co)
	Gamma absorption gauges for on-line coal sludge density	Mostly ^{137}Cs, but also ^{60}Co and ^{241}Am	0.1 (^{137}Cs); 0.03 (^{60}Co); 0.06 (^{241}Am)
	Basis weight and thickness	^{85}Kr	30
	Combined gamma backscatter and microwave gauge for basis weight and moisture	^{241}Am (3 GBq)	0.06
	Beta transmission airborne dust monitor	^{147}Pm (100 MBq)	40
	Neutron gauge for on-line sulphuric acid concentration measurement	$^{238}Pu/Be$ or $^{241}Am/Be$, (24 GBq)	0.06

TABLE I–1. NUCLEAR GAUGES: APPLICATIONS, RADIATION SOURCES AND D VALUES (cont.)

Type	Application	Typical radiation source(s)	D values (TBq) [I–1]
	Combined gamma and neutron gauge for S and Pb analysis in oil	^{244}Cm, ^{137}Cs and ^{241}Am/Be	0.05 (^{244}Cm); 0.1 (^{137}Cs); 0.06 (^{241}Am)
	Lumbar gamma density gauge	^{241}Am (11 GBq per measurement head)	0.06
	Gamma backscattering density gauge	^{137}Cs (19 MBq)	0.1
	Gamma nuclear gauge for sediment density measurement	^{241}Am or ^{137}Cs (200 MBq)	0.06 (^{241}Am); 0.1 (^{137}Cs)
	Gamma density meter gauge	^{137}Cs (200 MBq)	0.1 (^{137}Cs)
	Gamma transmission gauge for on-line fluid density measurement	^{241}Am, ^{137}Cs, ^{60}Co	0.06 (^{241}Am); 0.1 (^{137}Cs); 0.03 (^{60}Co)
	Gamma transmission gauge for sediment concentration measurement in rivers	^{241}Am, ^{137}Cs (10–30 MBq)	0.06 (^{241}Am); 0.1 (^{137}Cs)
	Gamma thickness gauge	^{137}Cs (0.2–1.5 TBq)	0.1
	Beta thickness gauge	^{147}Pm, ^{85}Kr, ^{90}Sr	40 (^{147}Pm); 30 (^{85}Kr); 1 (^{90}Sr)
	Beta thickness gauge (for aluminium)	^{90}Sr (3.7 GBq)	1
	Gamma conveyor belt weigher	^{241}Am (up to 3.7 GBq), ^{137}Cs (up to 1.2 GBq)	0.06 (^{241}Am); 0.1 (^{137}Cs)
	Basis weight gauge for paper processing (beta or X rays)	^{90}Sr, ^{85}Kr, X ray generators	30 (^{85}Kr); 1 (^{90}Sr)

TABLE I–1. NUCLEAR GAUGES: APPLICATIONS, RADIATION SOURCES AND D VALUES (cont.)

Type	Application	Typical radiation source(s)	D values (TBq) [I–1]
	Portable ‘XClad’ gauge for external corrosion of clad pipes	^{241}Am (in pairs)	0.06 (^{241}Am)
Dual energy gamma ray transmission gauge	On-line coal ash monitoring	^{137}Cs (0.4–1.1 GBq), ^{241}Am (3.7–11 GBq)	0.1 (^{137}Cs); 0.06 (^{241}Am)
Prompt gamma neutron activation analysis (PGNAA) gauges for on-line bulk processing	PGNAA on-line coal analyser	^{252}Cf (400 MBq)	0.02
	PGNAA cross-belt analyser for cement analysis	^{252}Cf (400 MBq)	0.02
	On-belt elemental neutron–gamma analyser for cement raw mill feed	^{241}Am/Be (2 × 370 GBq)	0.06
	PGNAA gauge for coal ash monitoring	^{137}Cs and ^{252}Cf	0.1 (^{137}Cs); 0.02 (^{252}Cf)
X ray fluorescence (XRF) gauges for elemental analysis	XRF in-stream analyser	X ray generators	n.a.[a]
	XRF on-site and laboratory analyser	^{109}Cd, ^{241}Am (1–3 GBq), X ray generators	20 (^{109}Cd); 0.06 (^{241}Am)
	Low energy gamma gauge	^{241}Am (20 GBq)	0.06
	Portable XRF elemental analyser	^{244}Cm (1.1 GBq), X ray generators	0.05
Combined nuclear–conventional gauges	Combined backscatter gamma gauge with microwave sensor for on-line coal monitoring	^{241}Am (3.7 GBq)	0.06

TABLE I–1. NUCLEAR GAUGES: APPLICATIONS, RADIATION SOURCES AND D VALUES (cont.)

Type	Application	Typical radiation source(s)	D values (TBq) [I–1]
	Combined gauge: gamma backscattering for ash and microwave for moisture	^{241}Am (1.9 GBq)	0.06
Portable density/ moisture Gauges	Road construction, landfills	^{137}Cs (370 MBq), ^{241}Am (1.9 GBq)	0.1 (^{137}Cs); 0.06 (^{241}Am)
Low activity gauges	Portable face and stockpile coal ash analyser	^{133}Ba (1.1 MBq) and ^{137}Cs (37 kBq or 370 kBq)	0.02 (^{133}Ba); 0.1 (^{137}Cs)
	Low gamma activity logging probe	^{137}Cs (0.37–1.1 MBq) and ^{133}Ba (1.9 MBq)	0.1 (^{137}Cs); 0.02 (^{133}Ba)
	Combined neutron and gamma gauge for soil surface moisture and density	^{60}Co (2.6 MBq) and ^{252}Cf (1.1 MBq)	0.03 (^{60}Co); 0.02 (^{252}Cf)
	Low activity gamma transmission gauge	^{60}Co (3.7 MBq)	0.03
	Combined gamma and neutron gauge for moisture and density	^{60}Co (2.6 MBq) and ^{252}Cf (1.1 MBq)	0.03 (^{60}Co); 0.02 (^{252}Cf)
	Subsurface gamma backscatter gauge for bulk density	^{60}Co (3.7 MBq)	0.03
	Gamma density gauge for soil	^{137}Cs (3.3 MBq), ^{60}Co (3.3 MBq)	0.1 (^{137}Cs); 0.03 (^{60}Co)
	Gamma–neutron gauge for density and moisture (low activity)	^{60}Co (2.6 MBq) and ^{252}Cf (1.1 MBq)	0.03 (^{60}Co); 0.02 (^{252}Cf)
	Gamma–neutron gauge for on-line flow concrete density and moisture (low activity)	^{60}Co (1.9 MBq) and ^{252}Cf (1.9 MBq)	0.03 (^{60}Co); 0.02 (^{252}Cf)

TABLE I–1. NUCLEAR GAUGES: APPLICATIONS, RADIATION SOURCES AND D VALUES (cont.)

Type	Application	Typical radiation source(s)	D values (TBq) [I–1]
	Combined gamma and neutron gauge for density and moisture in boreholes (low activity)	^{137}Cs (3.7 MBq) and ^{252}Cf (1.1 MBq)	0.1 (^{137}Cs); 0.02 (^{252}Cf)
	Combined gamma and neutron gauge for density and moisture in underground (low activity)	^{137}Cs (3.7 MBq) and ^{252}Cf (1.1 MBq)	0.1 (^{137}Cs); 0.02 (^{252}Cf)
	Gamma level gauge	^{60}Co (3.7 MBq)	0.03
	Gamma transmission density meter for on-line liquid density monitoring	^{137}Cs, ^{133}Ba (3.7 MBq)	0.1 (^{137}Cs); 0.02 (^{133}Ba)
Portable gamma tomograph	Pole inspection	^{241}Am (11 GBq)	0.06

[a] n.a.: not applicable.

TABLE I–2. NUCLEAR GAUGES USED IN MANUFACTURING INDUSTRIES

Applications	Techniques	Fields of application						
		Civil engineering	Packaging	Plastic, paper & pulp	Metal processing	Chemical & petrochemical	Safety	Miscellaneous
Level/fill	Gamma transmission		x	x	x	x		x
	Neutron backscatter			x		x		
Thickness and area weight	Gamma transmission				x			
	Beta transmission			x	x		x	
	Gamma backscatter			x				
	Beta backscatter			x	x			x
	XRF[a]				x			x
Density	Gamma transmission	x	x	x				x
	Gamma backscatter	x						x
Bulk weight	Gamma transmission	x						
Fluid flow	Gamma transmission (single and multi-energy)					x		x

TABLE I–2. NUCLEAR GAUGES USED IN MANUFACTURING INDUSTRIES (cont.)

Applications	Techniques	Fields of application						
		Civil engineering	Packaging	Plastic, paper & pulp	Metal processing	Chemical & petrochemical	Safety	Miscellaneous
Moisture	Gamma transmission	x						
	Neutron transmission	x						x
	Neutron moderation	x						x
Analysis	PGNAA[b]	x						x
	γ transmission	x					x	x
	XRF[a]				x	x	x	x
	Ionization						x	

[a] XRF: X ray fluorescence.
[b] PGNAA: prompt gamma neutron activation analysis.

REFERENCE TO ANNEX I

[I–1] EUROPEAN COMMISSION, 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 ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

Annex II

CONSIDERATIONS FOR A SAFETY ASSESSMENT AND LOCAL RULES FOR NUCLEAR GAUGES

SAFETY ASSESSMENT

II–1. To prepare a safety assessment for normal operational conditions and foreseeable incident scenarios, the associated hazards and control measures need to be considered and documented.

Normal operating conditions

II–2. For nuclear gauges, normal operating conditions include the following:

— Installation of gauges;
— Operation of gauges;
— Transport of portable gauges;
— Work at the client's site with portable gauges;
— Maintenance of gauges;
— Disposal of disused sources and gauges.

II–3. For each of the above operating conditions, the hazards involved and the necessary control measures need to be identified.

Reasonably foreseeable incidents

II–4. A set of reasonably foreseeable incidents are to be used as the postulated scenarios that are to be considered in the safety assessment, and for which appropriate safety measures are to be identified and implemented. The list of reasonably foreseeable incidents for nuclear gauges includes the following:

(a) Neutron generator or X ray generator failing to de-energize when operation is terminated;
(b) Loss of shielding resulting in increased dose rates;
(c) Damaged source resulting in the spread of radioactive contamination;
(d) Missing, lost or stolen radioactive source;
(e) Leaking source (e.g. as detected by a routine leak test);
(f) Failure of a safety system (e.g. warning lights, shutter mechanisms);
(g) Fire or explosion (work area, storage area, during transport);

(h) Incidents during special procedures (installation, maintenance, calibration, removal);
(i) Damaged transport container (for portable gauges);
(j) Accident during movement or transport of portable gauges containing radioactive material.

II–5. The elements to be considered in the safety assessment for each of these scenarios are discussed below.

Hazards

External radiation hazards

II–6. The nature of the external radiation hazard and the associated control measures will depend on the type of radiation emitted by the radiation sources in the gauge, as shown in Table II–1.

II–7. In terms of the sources listed in Table II–1:

— The beta sources will give rise to bremsstrahlung radiation.
— Some ^{241}Am gamma sources produce neutron radiation.
— The neutron sources will give rise to gamma radiation.

II–8. Gauges containing radiation generators will produce an external radiation hazard due to X rays or neutron radiation. Neutron generators will also give rise to gamma radiation.

Internal radiation hazards

II–9. There is potential for internal exposure if a sealed source were to be damaged. Beta sources, in particular, can be easily damaged. For gamma and neutron sources, damage is much less likely owing to the use of special form radioactive material. However, in a severe accident or owing to severe environmental conditions, even these sources might be ruptured, giving rise to potential internal exposure.

TABLE II–1. MAJOR ISOTOPES USED IN NUCLEAR GAUGES

Radionuclide	Type of radiation
Promethium-147	Beta
Thallium-204	Beta
Krypton-85	Beta
Strontium-90/Yttrium-90	Beta
Americium-241	Gamma
Caesium-137	Gamma
Cobalt-60	Gamma
Americium-241/Beryllium	Neutron
Californium-252	Neutron
Iron-55	X ray
Cadmium-109	X ray

Who would be exposed to the hazards?

II–10. Consideration is to be given to the following persons:

(a) Workers: Gauge operators, gauge maintenance personnel and other personnel present in the area.
(b) Members of the public, including visitors to the site.

Control measures

Engineered controls

II–11. Consideration is to be given to the following engineered controls:

(a) Safety incorporated in the design of the sealed source, the gauge and the gauging system as a whole;

(b) Shielding provided by the gauge and any associated containers;
(c) Demarcation of the gauge area with barriers and warning signs;
(d) Safety and warning systems (shutters, interlocks, warning lights and other signals);
(e) Design of special handling tools (for installation, maintenance and emergency procedures).

Administrative controls

II–12. Consideration is to be given to the following administrative controls:

(a) Safe working procedures, including local rules and permit-to-work systems;
(b) Staff training;
(c) Appointment of radiation protection officer(s);
(d) Obtaining advice from a qualified expert;
(e) Establishing a radiation protection programme, including the designation of controlled areas and supervised areas, and workplace monitoring and individual monitoring;
(f) Periodic maintenance and servicing of nuclear gauges;
(g) Periodic checks on the operation and effectiveness of safety systems;
(h) Periodic safety audits of operations;
(i) Establishment of dose investigation levels;
(j) Procedures for leak testing of radioactive sources;
(k) Inventories for radioactive sources and radiation generators, supported by periodic accountancy checks and records, and records of the movement of radiation sources.

LOCAL RULES

II–13. Local rules developed by the operating organization are expected to specifically address the actions to be taken and the persons responsible. A sample structure of the local rules is provided in Table II–2 indicating some of the important elements.

TABLE II–2. LOCAL RULES FOR NUCLEAR GAUGES: SUGGESTED TABLE OF CONTENTS

Section	Contents
Introduction	Who do the local rules apply to? Which gauges or areas do they cover? Which regulations apply?
Procedures for transport of gauges containing radioactive sources (if applicable)	Preparation to consign a radioactive source Transport package requirements Marking, labelling and other control measures Transport documentation including emergency procedures Transport management system Arrangements for receipt of a radioactive source
Procedures for storage and source accountancy	Description of storage facilities and storage containers for radioactive sources Security aspects (e.g. key control) Designation of storage areas and warning signs Periodic physical inventory checks of sources Record keeping for source accountancy Record keeping for source movements
Procedures for control of exposure	Description of controlled areas and supervised areas Workplace monitoring programme Arrangements for individual dosimetry and health surveillance (if applicable) Dose investigation level
Calibrations, testing and maintenance	Annual testing of workplace monitoring instruments Preventive maintenance programme for gauges Testing of warning and safety systems Leak testing of radioactive sources
Roles and responsibilities, and contact details	Relevant managers Workers operating the gauges Radiation protection officer Qualified expert Regulatory body Gauge supplier and maintenance organizations Security officer
Emergency procedures	Roles and responsibilities Immediate actions to be taken Emergency contact details

Annex III

EXAMPLES OF INCIDENTS INVOLVING NUCLEAR GAUGES

EXAMPLE 1: SOURCE FALLS OUT OF QUARRY LEVEL GAUGE[1] [III–1]

Description of the incident

III–1. The incident involved a level gauge containing a 1.85 GBq ^{137}Cs source. The source fell out of the shielded housing onto the ground below. A worker subsequently picked up the source and took it to a control room, where it remained for almost two days.

III–2. The presence of an unshielded source was eventually recognized by a supervisor who was investigating the non-operation of the gauge. He immediately threw the source out of the window, after which he buried it in a soft mud bank, around which he set up an appropriate exclusion zone.

III–3. The source was subsequently recovered by a qualified expert and placed in a shielded container.

Doses to workers

III–4. Workers did not wear personal dosimeters. Dose rate measurements and a reconstruction of the incident were used to estimate the doses received by the worker and the supervisor. The results are given in Table III–1; the doses received could have been considerably higher.

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[1] The European ALARA Network (EAN) web site (www.eu-alara.net/index.php) includes links to the EAN newsletters from which the reports of incidents described in this Annex have been obtained. The same web site also includes a direct link (www.eu-alara.net/index.php/incidents-lessons-learned-mainmenu-45.html) to the OTHEA database (www.othea.net) that contains a larger collection of radiological incidents involving nuclear gauges. The incident reports are anonymous and have been selected to provide interesting and useful lessons, with the aim of preventing similar incidents in the future and mitigating the consequences of such incidents if they were to occur.

TABLE III–1. DOSES TO WORKERS

Person	Estimated whole body effective dose	Estimated equivalent dose to finger
Worker	2−3 mSv	300 mSv max.
Supervisor	0.05 mSv	0.04 mSv max.

Lessons identified

III–5. Nuclear gauges are a very common application, and it is extremely rare for the source to fall out under normal operating conditions. In this case, the source housing was subject to constant vibration, and this was a major factor in a securing bolt becoming loose. This problem can be addressed at the design stage, for example through the addition of a locking pin. Operating organizations also need to ensure that regular checks on the integrity of source housings are undertaken, especially where harsh environmental factors exist.

III–6. An early indication of the loss of the source was provided by the failure of the gauge system itself. Gauge operating staff need to be aware of this and put procedures in place to immediately check the location of the source in the event of such a failure.

III–7. Providing workers with suitable information, instruction and training is important — even for those who do not directly work with radiation sources. In this case, simple radiation awareness training (including the location of the sources on the site, a description of what the sources look like inside and outside their containers, basic precautions and whom to contact) could have helped avoid any radiation exposures.

EXAMPLE 2: SOURCES DAMAGED WHEN REMOVED FROM LEVEL GAUGES, LEADING TO CONTAMINATION [III–2]

Description of the incident

III–8. As part of a refurbishment of a brewery, four liquid level gauges, each containing a 3.7 GBq ^{241}Am source, were removed from a production line and put inside a store before disposal. The sources were beyond their recommended working life, were no longer certified as special form radioactive material, and required a Type B container for transport from the site.

III–9. The ^{241}Am source assembly of each gauge was sandwiched between stainless steel plates, attached to which were a shutter mechanism and mounting bracket. The radioactive material was incorporated within a thin-walled, stainless steel tube.

III–10. The company that was contracted to dispose of the sources brought only one Type B container to the site. The contractor intended to dismantle the gauges on the site and transport all four ^{241}Am sources in one consignment. It was discovered that the source assemblies, which were each about 2 cm long, were fixed in place with adhesive. The contractor’s employee forced them out of their housing using a screwdriver and placed them in the Type B container. The sources were damaged in the process.

III–11. The work was performed in the back of a vehicle in the car park of the brewery. The driver then went to a second location about 200 km away to collect some more sources for disposal before travelling to the disposal company site.

III–12. A few days later, it was discovered that the container and the vehicle were contaminated with ^{241}Am. Subsequent monitoring revealed that the contamination was more extensive, and included other vehicles and other premises (including homes). The company reported the incident and a detailed investigation commenced. The investigation showed the following:

(a) The contractor did not discuss the job with the brewery or with the contractor’s qualified expert and had inaccurate information about the size of the gauges and the sources.
(b) Alternative methods of work had not been considered.
(c) There was doubt about whether the available workplace monitoring instrument was functional; when the batteries of the instrument were checked some days later these were found to be completely discharged.

Radiological consequences

III–13. The doses received were primarily due to intakes of ^{241}Am; the committed effective dose equivalents were estimated to be 20 mSv and 2 mSv for two workers of the disposal contractor, and below 1 mSv for the wife of the first worker.

Lessons identified

III–14. The following lessons were identified from the incident:

(a) Equipment holding radioactive sources needs, wherever possible, to be transported with the source undisturbed to suitable facilities before dismantling takes place.
(b) Where removal of sources on the site is unavoidable, close liaison between all the operating organizations involved (and their respective qualified experts) needs to take place with a view to ensuring that adequate facilities are available for the work to proceed safely.
(c) Local rules have to clearly and unambiguously state what needs to be done (or not done) if conditions change during the work.
(d) Emergency procedures need to be incorporated into local rules, made known to relevant persons, and practised.
(e) After source manipulations, appropriate monitoring needs to be undertaken. In situations such as this, contamination always needs to be considered possible; not just from the manipulation procedure, but also owing to degradation of the sources due to the environment in which they were used.
(f) The operation of workplace monitoring instruments needs to be checked before each use (e.g. using a check source). Spare batteries have to be carried with the instrument.

EXAMPLE 3: LOSS OF SHUTTER CAUSING EXPOSURE OF MEMBERS OF PUBLIC [III–3]

III–15. An operating organization reported that the shutter on a gauge that was inside the cupola of a refractory had fallen off, resulting in the exposure of members of public. The gauge contained a 300 GBq ^{137}Cs source.

III–16. Inspectors from the regulatory body visited the site and established that a total of 10 persons had been exposed to radiation; the initial estimated effective doses ranged from 0.5 to 13 mSv. The final dose estimate confirmed that four persons received doses greater than 10 mSv.

III–17. The gauge was removed, the shielded shutter was welded back in place, and the gauge was sent back to the manufacturer for failure analysis. The analysis revealed that the shutter was badly corroded and rusted, which was unexpected because it was only five years old.

III–18. A contributing factor in the failure was maintenance work that occurred while the gauge was still attached to the cupola. The operating organization used pneumatic chipping hammers to remove a refractory brick layer from inside the cupola. It is believed that the vibrations caused the badly rusted and corroded shield to fall off. The gauge location was such that visual inspections were difficult.

III–19. To prevent a recurrence of the incident, the operating organization received a new gauge housed in stainless steel with a stainless steel shutter.

III–20. The operating organization arranged to have the gauges removed by a licensed service provider if work on the cupola requires pneumatic hammers or other vibrational work. While the sources are removed, the service provider will inspect the gauges for signs of corrosion or other signs of damage or potential failure.

III–21. The gauge has been placed in the same location where visual inspections are difficult. Consequently, if no work requiring gauge removal occurs within three years from the last inspection, the operating organization has arranged for a service provider visit the facility for the purpose of removing the gauges to perform a thorough visual inspection.

REFERENCES TO ANNEX III

[III–1] EUROPEAN COMMISSION, European ALARA Newsletter, Issue 17 (2005), www.eu-alara.net/images/stories/Newsletters/alaranewsletter17.pdf

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