IAEA Safety Standards

for protecting people and the environment

Radiation Safety in Industrial Radiography

Specific Safety Guide

No. SSG-11

IAEA
International Atomic Energy Agency

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IAEA SAFETY STANDARDS SERIES No. SSG-11

RADIATION SAFETY IN INDUSTRIAL RADIOGRAPHY

SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2011

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FOREWORD

by Yukiya Amano
Director General

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

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

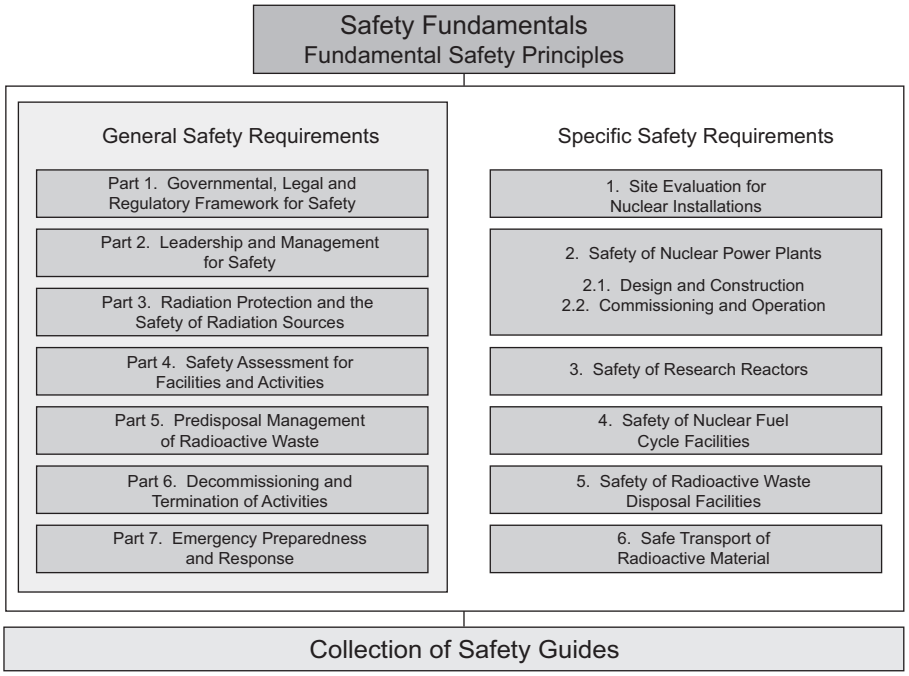

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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 is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as 'should' statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety

standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

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

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

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

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

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

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

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

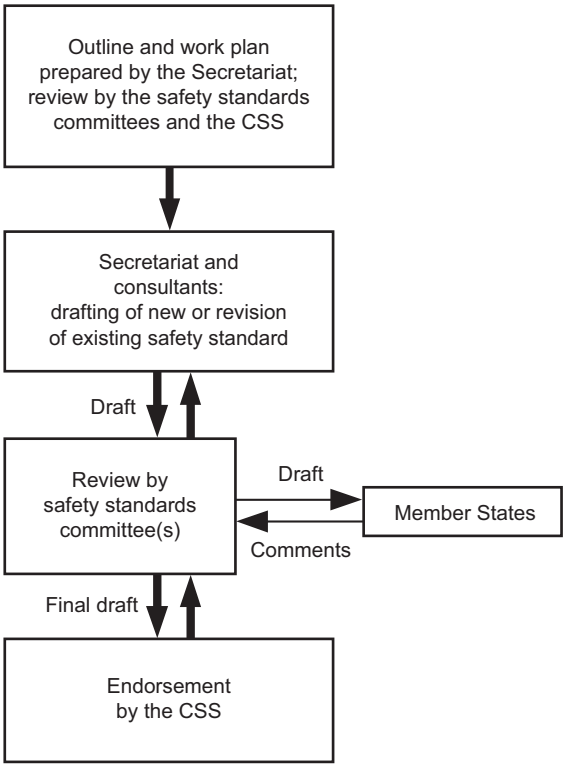

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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

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

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international

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

INTERPRETATION OF THE TEXT

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

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

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

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

CONTENTS

1. INTRODUCTION 1

Background (1.1–1.5). 1
Objective (1.6–1.7). 2
Scope (1.8–1.11) 2
Structure (1.12–1.14) 3

2. DUTIES AND RESPONSIBILITIES 4

General (2.1) 4
The operating organization (2.2–2.12). 4
Radiation protection officers (2.13–2.15) 7
Qualified experts (2.16–2.18) 8
Workers (2.19–2.25) 8
The client (2.26–2.30) 10

3. SAFETY ASSESSMENT 11

General (3.1–3.3) 11
Methodology for the safety assessment (3.4). 12
Outcomes of the safety assessment (3.5) 12
Reviews of the safety assessment (3.6) 13

4. RADIATION PROTECTION PROGRAMME 13

Objectives and scope (4.1–4.3) 13
Structure and content (4.4–4.5) 14
Management structure and policies (4.6–4.27) 14
Record of the safety assessment (4.28) 19
Radiation safety committee (4.29) 19

5. TRAINING AND QUALIFICATION 20

General (5.1–5.2) 20
Design of a training programme (5.3–5.5). 20
Structure and content of the training course (5.6–5.7). 21
Refresher training (5.8–5.9) 22

6. INDIVIDUAL MONITORING OF WORKERS 23

Individual dose assessment (6.1–6.5) 23
Personal alarm monitors (6.6–6.9) 24
Direct reading dosimeters (6.10–6.14) 25
Record keeping (6.15–6.18) 26
Investigation of doses (6.19) 27
Health surveillance (6.20) 27

7. WORKPLACE MONITORING 27

Programme of monitoring (7.1–7.2) 27
Selection, maintenance and calibration of survey meters (7.3–7.7) . . . 28

8. CONTROL OF RADIOACTIVE SOURCES (8.1–8.6) 30

9. SAFETY OF INDUSTRIAL RADIOGRAPHY SOURCES AND EXPOSURE DEVICES 31

General (9.1–9.3) 31
Gamma radiography sources and exposure devices (9.4–9.36) 32
X ray generators (9.37–9.50) 39

10. RADIOGRAPHY IN SHIELDED ENCLOSURES 43

General (10.1–10.3) 43
Design and shielding (10.4–10.12) 44
Controlled and supervised areas (10.13–10.14) 45
Safety systems and warning systems for gamma radiography (10.15–10.24) 46
Safety systems and warning systems for X ray generators (10.25–10.33) 47
Procedures for radiography (10.34–10.44) 49
Decommissioning (10.45) 51

11. SITE RADIOGRAPHY 52

General (11.1–11.4) 52
Preparation for site radiography (11.5–11.6) 53
Cooperation with the client (11.7–11.10) 53

Demarcating the boundary of the controlled area (11.11–11.15) 54
Warning signals (11.16–11.17) 54
Notices (11.18). 55
Patrolling and monitoring the boundary (11.19–11.21). 55
Monitoring (11.22–11.26) 56
Additional precautions for site gamma radiography (11.27–11.39) . . . 57
Additional precautions for site X ray radiography, including the use of accelerators (11.40–11.44) 59

12. TRANSPORT OF RADIOACTIVE SOURCES 60

Movement within the worksite (12.1–12.2). 60
Transport to another site (12.3–12.9). 61

13. EMERGENCY PREPAREDNESS AND RESPONSE 62

General (13.1–13.6) 62
Development of emergency plans (13.7–13.10) 63
Types of emergency (13.11–13.13) 64
Content of a basic emergency plan (13.14–13.16). 65
Emergency equipment (13.17–13.19) 66
Specific emergency procedures (13.20–13.21) 67
Training and exercises (13.22–13.24) 69
Periodic reviews of plans and equipment (13.25–13.26). 70
Reporting (13.27–13.30) 70

APPENDIX: IAEA CATEGORIZATION OF RADIOACTIVE SOURCES 73

REFERENCES 77

ANNEX I: EXAMPLE OF A SAFETY ASSESSMENT. 81

ANNEX II: OVERVIEW OF INDUSTRIAL RADIOGRAPHY SOURCES AND EQUIPMENT 87

ANNEX III: EXAMPLES OF ACCIDENTS IN INDUSTRIAL RADIOGRAPHY 91

CONTRIBUTORS TO DRAFTING AND REVIEW 99
BODIES FOR THE ENDORSEMENT
OF IAEA SAFETY STANDARDS 101

1. INTRODUCTION

BACKGROUND

1.1. The applications of ionizing radiation bring many benefits to humankind, ranging from power generation to uses in medicine, industry and agriculture. One of the longest established industrial applications of radiation is the use of radiography for the non-destructive testing of items of equipment. Industrial radiography provides a means of verifying the physical integrity of equipment and structures such as vessels, pipes, welded joints, castings and other devices. The structural integrity of such equipment and structures affects not only the safety and quality of the products but also the protection of workers, the public and the environment.

1.2. Industrial radiography work poses a negligible risk if it is performed in a safe manner. However, experience shows that incidents involving industrial radiography sources have sometimes resulted in high doses to workers, causing severe health consequences such as radiation burns and, in a few cases, death. Members of the public have also suffered radiation overexposures when radioactive sources used for industrial radiography were not properly controlled or regulated. Contamination of people and the environment has also resulted from incidents involving corroded or damaged sources. Industrial radiography work by its nature is often carried out under difficult working conditions, such as in confined spaces or extreme cold or heat. Working under such adverse conditions might result in operational situations in which the principle of keeping doses as low as reasonably achievable is challenged. All of these aspects demonstrate the necessity for senior management to promote a safety culture within their organizations to ensure that safety comes first.

1.3. It is assumed in this Safety Guide that the State has in place an effective governmental, legal and regulatory infrastructure for radiation safety that covers industrial radiography[1] [1–4].

[1] The term 'industrial radiography' is used in this Safety Guide to mean industrial radiography involving radiation sources. 'Radiation' as used here means ionizing radiation. The terminology used in this publication is defined and explained in the IAEA Safety Glossary, 2007 Edition [5] (see also http://www-ns.iaea.org/standards/safety-glossary.htm).

1.4. This Safety Guide supersedes Safety Reports Series No. 13 on Radiation Protection and Safety in Industrial Radiography[2].

1.5. Unless otherwise stated, terms are used with the meanings ascribed to them in the IAEA Safety Glossary (2007 Edition) [5].

OBJECTIVE

1.6. The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the BSS) [2] specify the basic requirements for protection of people against exposure to radiation and for the safety of radiation sources. The implementation of these requirements helps to ensure that the number of people exposed to radiation and their doses are kept as low as reasonably achievable, and helps to prevent incidents or to mitigate their consequences. This Safety Guide recommends how industrial radiography work should be carried out within the framework of the BSS and other IAEA safety standards.

1.7. The guidance in this publication is based on the BSS and other IAEA safety standards which are referenced in the text. The guidance in this publication is aimed primarily at managers of operating organizations that are authorized to carry out industrial radiography work, radiographers, radiation protection officers and regulators. The guidance may also be of interest to designers and manufacturers of industrial radiography equipment and facilities.

SCOPE

1.8. This Safety Guide provides recommendations for ensuring radiation safety in industrial radiography used for purposes of non-destructive testing. This includes industrial radiography work that utilizes X ray and gamma sources, both in fixed shielded facilities that have effective engineering controls and outside shielded facilities using mobile sources (i.e. site radiography).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety in Industrial Radiography, Safety Reports Series No. 13, IAEA, Vienna (1999).

1.9. Recommendations and guidance relating to techniques of industrial radiography, such as techniques for obtaining a good image, are provided in another IAEA publication [6].

1.10. The use of gamma radiography underwater and the use of neutron radiography are relatively rare. These techniques will require the development of specialized safety assessments and specific procedures. The technical guidance for these radiography techniques are not specifically addressed in this publication, although the general safety principles apply, such as provision of adequate shielding and ensuring that radiation doses are kept as low as reasonably achievable.

1.11. The use of radiation for security screening of people and of baggage, mail, cargo and vehicles and for other such detection purposes is planned to be covered in a separate IAEA Safety Guide.

STRUCTURE

1.12. The various duties and responsibilities of organizations and individuals are described in Section 2. The preparation of a safety assessment and its relationship to the radiation protection programme are covered in Sections 3 and 4, respectively. The necessity for operating organizations to employ trained and qualified personnel is described in Section 5. Sections 6 and 7, respectively, describe how radiation monitoring of workers and the workplace should be carried out.

1.13. Subsequent sections detail the practicalities of properly controlling gamma sources (Section 8), the physical safety of gamma and X ray sources and ancillary equipment (Section 9), the safe use of X ray and gamma sources in fixed facilities and under conditions for site radiography (Sections 10 and 11, respectively), and the safe transport of radioactive sources (Section 12). Preparedness for, and response to, emergencies involving industrial radiography sources are described in Section 13.

1.14. A summary of the IAEA categorization of radioactive sources is given in the Appendix. An example of safety assessment for industrial radiography is given in Annex I. An overview of industrial radiography sources and equipment is provided in Annex II. Finally, a short overview of examples of accidents is given in Annex III.

2. DUTIES AND RESPONSIBILITIES

GENERAL

2.1. The overall responsibility for radiation safety lies with the operating organization that is authorized to carry out industrial radiography work. Specific duties and the day to day responsibilities for safe operation of the equipment will, however, lie with a range of people, including senior management, the radiation protection officer, industrial radiographers and assistants, qualified experts and, for site radiography work, the client responsible for the premises where the site radiography work is being carried out and any relevant subcontractors. All responsibilities and duties should be agreed to by all relevant parties and should be identified in writing.

THE OPERATING ORGANIZATION

Management of radiation safety and safety culture

2.2. The operating organization, through its managers, is responsible for the establishment and implementation of the technical and organizational measures necessary to ensure protection and safety and for compliance with the relevant legal and regulatory requirements. In some cases, it may be appropriate to appoint people from outside the organization to carry out tasks or actions in relation to these responsibilities, but the operating organization retains the prime responsibility for radiation safety and regulatory compliance.

2.3. A senior manager should be designated as having overall responsibility for overseeing radiation safety and verifying that industrial radiography work is carried out in accordance with regulatory requirements. Responsibilities for radiation safety are required to be established, and they should be agreed to by all relevant parties and recorded in written form. Managers should ensure that procedures are in place for the protection of workers, the public and the environment, and for ensuring that doses are kept as low as reasonably achievable (the principle of optimization). All policies and procedures should be documented, and should be made available to all staff and the regulatory body as appropriate.

2.4. Managers are required to foster a safety culture within their organization, to encourage a questioning and learning attitude to protection and safety and to discourage complacency [2]. A good safety culture is promoted by management arrangements and workers' attitudes, which interact to foster a safe approach to the performance of work. Safety culture is not confined to radiation protection; it should also extend to conventional safety.

2.5. Operating organizations with a good safety culture do not assign blame when incidents occur; they learn from their mistakes, foster a questioning attitude and seek continuous improvement in the safety of work processes. In investigating incidents, consideration may be given to what is acceptable behaviour; however, in some cases, disciplinary measures may be taken.

Radiation protection programme

2.6. The operating organization should develop, document and implement a radiation protection programme [7]. This should include information on the radiation protection arrangements, the safety assessment, the measures for implementing the arrangements, and the mechanism for the review and updating of the arrangements. Further details on the safety assessment and the radiation protection programme are given in Sections 3 and 4, respectively.

Management system

2.7. The operating organization should develop, implement, assess and continually improve a management system that defines the responsibilities of all relevant persons and details the requirements for the organization, personnel and equipment. The management system should be based on national or international standards [8–10]. It should incorporate mechanisms for routine internal inspections and audits, as well as third party audits, as appropriate. The radiation protection programme should be integrated into the management system.

Facilities and resources

2.8. The operating organization should ensure that suitable facilities and equipment are available, to enable radiography work to be carried out safely and in accordance with regulatory requirements. In particular, radiography equipment should incorporate all the relevant safety features and warning features. An adequate number of radiographers, assistants and radiation protection officers should be available to perform each job safely. They should be provided with

appropriate equipment (such as radiation monitors) to enable the work to be carried out safely and effectively.

Notification to the regulatory body

2.9. The operating organization intending to carry out industrial radiography work should submit a notification to the regulatory body of its intention to carry out work of this type. This notification should be made prior to the commencement by the operating organization of work with radiation, and the details of the notification should be in accordance with regulatory requirements. Some regulatory bodies may require additional information to be provided on a regular basis or on a case by case basis (e.g. for site radiography work).

Authorization from the regulatory body

2.10. The operating organization is required to apply to the regulatory body for an authorization to acquire, store, use, distribute or transfer radiography sources. Some States may also require an authorization for the import or export of radiography sources. Radiography work should not commence until the appropriate authorization, which may impose certain restrictions or limitations, has been received by the operating organization.

2.11. When applying for an authorization, the operating organization should provide the regulatory body with the appropriate documentary evidence to demonstrate that an adequate level of radiation safety will be afforded and maintained. Regulatory bodies, if not accepting an implicit justification, should require a formal justification from the operating organization for the use of ionizing radiation rather than alternative technologies for purposes of non-destructive testing.

2.12. The documentary evidence necessary to support an authorization request should include, as a minimum:

(a) Information about the applicant for authorization;
(b) The operating organization's requirements for the training and qualification of all relevant staff;
(c) Technical information about the type(s) of radiation source(s) and equipment to be used;
(d) A safety assessment covering the use and storage of sources;
(e) Details of the safety system and facilities in which the radiation sources will be stored or used (e.g. shielding, interlock systems and warning systems);

(f) A radiation protection programme;
(g) Emergency plans and procedures.

RADIATION PROTECTION OFFICERS

2.13. The operating organization should appoint in-house at least one employee as a radiation protection officer to oversee the day to day implementation of the radiation protection programme and to carry out the duties required by the programme. The duties of the radiation protection officer, depending on the regulatory requirements, may include:

(a) Oversight of industrial radiography operations, to assist the operating organization to comply with regulatory requirements, including requirements for the safe transport of sources for site radiography work;
(b) Maintenance of source accountancy records;
(c) Inspection and maintenance of engineering controls, safety features and warning features;
(d) Oversight of access control for controlled areas;
(e) Establishment and periodic review of arrangements for personal dosimetry, including maintenance and review of occupational dose records;
(f) Ensuring that radiographers are suitably trained in the use of equipment and in radiation protection, and that they receive regular refresher training;
(g) Ensuring that emergency plans are established and that they are practised regularly;
(h) Supervision of workplace monitoring arrangements;
(i) Establishment, issue and periodic review of local rules (including work permits where appropriate);
(j) Investigation of higher than usual exposures and overexposures;
(k) Investigation and reporting of incidents, including accidents.

2.14. The number of radiation protection officers to be appointed will depend on the size of the operating organization, the number of radiography sources, and the frequency and nature of the radiography work to be carried out. In cases where more than one radiation protection officer has been appointed, the duties and responsibilities of each should be well defined. Even in small organizations consisting of only a few employees, someone with adequate knowledge, training and experience should be appointed as the radiation protection officer.

2.15. The radiation protection officer should be an employee of the company, should be appropriately qualified, should have experience of radiography and

should have a role that permits close oversight of radiography work. The operating organization should ensure that the radiation protection officer is afforded sufficient time, authority and resources to carry out their duties effectively. The radiation protection officer should also be given the authority to stop unsafe work and to interact effectively throughout the organization, especially with senior managers, to ensure that decisions that may affect radiation safety have high level support.

QUALIFIED EXPERTS

2.16. The operating organization may consult with one or more qualified experts on matters relevant to radiation safety, such as the design of radiography facilities, radiation shielding calculations, and testing and maintenance of radiation survey meters. The responsibility for compliance with regulatory requirements cannot be delegated to the qualified expert and always remains with the operating organization.

2.17. Qualified experts do not have to be employees of the operating organization: they may be appointed on a part-time basis or for specific projects. The primary necessity is that the qualified expert should satisfy any appropriate national qualification or certification criteria.

2.18. 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

Radiographers

2.19. While the primary responsibility for radiation safety lies with the operating organization, radiographers (including assistants and trainees) have a responsibility to work safely and to take all reasonable actions to restrict their own exposure and those of other workers and members of the public.

Radiographers should:

(a) Follow the local rules (see Section 4) and any relevant procedures;
(b) Wear their individual dosimeters in the correct place at all times during radiography work and source manipulation (see Section 6);

(c) Use radiation monitors properly and in a systematic manner (see Section 7);
(d) Cooperate with the radiation protection officer and qualified experts on all radiation safety issues;
(e) Participate in any training concerning radiation safety;
(f) Abstain from any wilful action that could put themselves or others in contravention of regulatory requirements or of the operating organization's own requirements.

2.20. The radiographer should promptly inform the radiation protection officer of any incident or circumstances that could result in higher than usual radiation doses to themselves or to other persons. This could include failures or observed deficiencies in safety systems and warning systems, errors in following procedures, or inappropriate behaviour. A written report should be made to the radiation protection officer as soon as practicable after the incident or observation.

2.21. Radiation safety should be incorporated into the daily routine of radiography work by all personnel. This is a factor by which the overall safety culture of the operating organization should be judged.

Radiographers on short term contracts (itinerant workers)

2.22. Operating organizations that hire self-employed radiographers on a short term basis should ensure that the radiographers have the same level of protection and safety as radiographers employed on a full-time basis. These short term radiographers (sometimes called itinerant workers) work for only a short period of time (e.g. several weeks) with the operating organization before leaving to work for another employer.

2.23. Such working practices can create particular difficulties in relation to regulatory compliance. The relevant responsibilities of the operating organization and the itinerant radiographer should be clearly specified in the contractual arrangements. To enable them to comply with regulatory requirements, operating organizations should be aware of itinerant workers' current annual cumulative effective dose prior to their commencing work.

2.24. The responsibilities of the operating organization and the itinerant radiographer will depend on the specific regulatory requirements. The operating organization should clarify with the radiographer the allocation of responsibilities for subjects such as:

— The provision of individual dosimetry and dose record keeping (see Section 6);
— Health assessment arrangements (see Section 6);
— Workplace monitoring arrangements (see Section 7);
— Local rules (see Section 4).

2.25. The operating organization should verify that the radiographer has the appropriate qualifications and has received the necessary training in both radiation safety and industrial radiography techniques. It should verify that all procedures and other relevant documents are provided in a language known to the radiographer.

THE CLIENT

2.26. The client is the organization or person responsible for hiring the operating organization to perform industrial radiography work. The client should always use an operating organization that is authorized by the regulatory body in accordance with regulatory requirements for industrial radiography.

2.27. The client should give the operating organization sufficient lead time to plan the work and to carry it out safely, and to enable compliance with any advance notifications required by the regulatory body.

2.28. The client should not impose contractual conditions or limitations that would hinder the operating organization from performing radiography work in a safe manner. Regulatory requirements and safety requirements take precedence over commercial requirements. The client should ensure that radiography work is coordinated with other work on-site, to minimize the risks to radiographers arising from site specific hazards and to minimize radiation exposures to other workers. There should be special coordination if more than one radiography organization is working on the client's site at one time. A permit-to-work system can facilitate communication and coordination of different jobs on the same site.

2.29. The client is responsible for ensuring a safe working environment for the radiographers, including the provision of scaffolding, adequate lighting and safe arrangements for working in vessels, confined spaces, trenches or other places where access might be necessary. The client is also responsible for informing visiting radiographers about safety issues that are site specific and/or providing them with any necessary training thereon.

2.30. If radioactive sources are to be stored temporarily on the client's site, both the client and the operating organization should ensure that such stores are safe and secure, and that any necessary authorizations are obtained from the regulatory body. Procedures for gaining access to the source store should be clearly defined in relation to the client and the operating organization. (See also Section 7.)

3. SAFETY ASSESSMENT

GENERAL

3.1. The operating organization should conduct and document a safety assessment for each type of radiation source for which they are authorized. For sources and devices of an identical type, it may be acceptable to make one generic safety assessment. The initial safety assessment, sometimes called a 'prior radiological evaluation', is the primary tool for determining which protection measures should be taken, and for confirming that all parameters that have a bearing on protection and safety are considered. The safety assessment should be documented and independently reviewed within the operating organization's management system.

3.2. A safety assessment should be carried out before the source is first received at the site or before it is used for the first time. The operating organization should plan ahead, to ensure that there is sufficient time for the required protection and safety measures to be put into place. A new safety assessment may not be necessary for the replacement of one source with an identical one.

3.3. In the event of work already being carried out where no safety assessment has previously been made, the operating organization should carry out a retrospective safety assessment. The retrospective safety assessment should either confirm that all the relevant protective measures are in place or identify any additional measures that should be put in place.

METHODOLOGY FOR THE SAFETY ASSESSMENT

3.4. Industrial radiography sources produce high dose rates and hence should be subject to a comprehensive safety assessment. The radiation risks arising from routine use of the radiation source(s) together with the probability and magnitude of potential exposures arising from incidents should be taken into account in the safety assessment. An example of a safety assessment for industrial radiography is given in Annex I. The safety assessment should include:

(a) Consideration of the dose rates from both shielded and unshielded radioactive sources and X ray generators;
(b) Potential exposures of radiographers, other workers and the public, for a range of scenarios representing normal use and reasonably foreseeable incidents;
(c) Limits and technical conditions for operation of sources;
(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;
(e) Ways in which external factors could affect protection and safety;
(f) Ways in which operating errors and human factors could affect protection and safety;
(g) Evaluation of the implications of any proposed modifications for protection and safety.

OUTCOMES OF THE SAFETY ASSESSMENT

3.5. The safety assessment should provide a basis for decision making in relation to:

(a) The engineered control measures that are required for safety;
(b) The development of procedures to be followed by the radiographers (the local rules);
(c) Requirements and procedures for designating controlled areas and supervised areas;
(d) Any requirements for protection of the public;
(e) Information on reasonably foreseeable incidents, including the measures required to minimize the likelihood of these incidents occurring and the necessary emergency equipment;

(f) Information on actions to be taken to restrict exposures of people and for protection of the environment in an incident (including emergency preparedness plans).

REVIEWS OF THE SAFETY ASSESSMENT

3.6. The safety assessment should be reviewed whenever any of the following factors apply:

(a) Safety may be compromised or affected as a result of modifications to facilities or to procedures, or the acquisition of a new radiation source or a source with different radiation characteristics.
(b) Operating experience or investigation of emergencies or incidents, failures or errors indicates that current safety measures are invalid or are not fully effective.
(c) Any significant changes to relevant guidelines, standards or regulations have been made or are envisaged.

4. RADIATION PROTECTION PROGRAMME

OBJECTIVES AND SCOPE

4.1. The radiation protection programme is a key factor in relation to the development and maintenance of safety culture within an organization [7], and it should meet the regulatory requirements. The radiation protection programme should cover the operating organization's management structure, policies, responsibilities, procedures and organizational arrangements. All of these are in place to control radiation hazards, to optimize radiation protection measures, to prevent or reduce exposures, and to mitigate the consequences of incidents.

4.2. 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 activities planned to be conducted for radiography purposes. The programme should be based on the operating organization's safety assessment, and it should address both planned exposure situations and potential exposures.

4.3. The elements of a radiation protection programme described here are representative of routine radiography operations with X ray and gamma sources. Operating organizations should take into account any additional measures and programmes necessary to address unique or unusual workplace hazards.

STRUCTURE AND CONTENT

4.4. The radiation protection programme should cover the main elements contributing to protection and safety. The structure and contents of the radiation protection programme should be documented to an appropriate level of detail. The radiation protection programme should include as essential elements:

(a) Management structure and policies;
(b) Assignment of individual responsibilities for radiation safety;
(c) Education and training programme on the nature of the radiation hazards, and protection and safety;
(d) Local rules and supervision;
(e) Designation of controlled or supervised areas;
(f) Arrangements for monitoring workers and the workplace, including the acquisition and maintenance of instruments for radiation protection purposes;
(g) A health surveillance programme;
(h) A system for recording and reporting all relevant information relating to the control of exposures, decisions regarding measures for occupational radiation protection and safety, and monitoring of individuals;
(i) Emergency preparedness plans;
(j) Methods for periodically reviewing and auditing the performance of the radiation protection programme;
(k) Quality assurance and process improvement.

4.5. These elements of a radiation protection programme, which are more fully described in the following, may be incorporated into a single document or a series of documents, depending on the scale and complexity of operations.

MANAGEMENT STRUCTURE AND POLICIES

4.6. The radiation protection programme should include a description of the management structure as it relates to radiation safety. This structure, which may be presented in the form of an organizational chart, should show the names of the

senior managers responsible for radiation safety and of the various duty holders (e.g. the radiation protection officer). The chart should clearly show the line of reporting, from the radiographer through to the senior manager with overall responsibility. If the operating organization has more than one location of operations, the management structure should clearly specify the responsible persons at each location.

4.7. The radiation protection programme should include the company policies on radiation safety, and should include a commitment by the management to keeping radiation doses as low as reasonably achievable and to fostering a safety culture.

Assignment of responsibilities for radiation safety

4.8. Responsibilities for radiation safety should be assigned to cover the entire lifetime of sources, from ordering and receipt, use and storage, to their eventual return to the supplier (or other possible end-of-life considerations). The posts for which responsibilities are allocated should include the senior managers of the operating organization (which has the prime responsibility for safety), the radiation protection officer, the qualified expert, radiographers and other workers, as described in Section 2.

4.9. For operating organizations performing radiography work on a client's premises, complying with some safety requirements (e.g. for the provision of information in relation to site specific hazards and safety requirements) should, where appropriate, be the responsibility of the client company rather than of the operating organization. At least one person from the industrial radiography organization should be given the responsibility to liaise with the client. This liaison process should include the identification of any hazards on the site, discussion of local rules, and exchange of safety related information.

Programme of education and training

4.10. The radiation protection programme should describe the full scope of the training programme in protection and safety for all employees directly involved in routine radiography activities and emergency operations (see Section 5). It should include a radiation 'awareness' programme, where appropriate, for other staff. Other staff includes managers, radiographers, trainees, workers such as cleaners and maintenance staff who may be inadvertently exposed, and contractors. The radiation protection programme should also specify the minimum educational and professional qualifications for all relevant staff,

especially the radiation protection officer, radiographers and their assistants, in accordance with regulatory requirements.

4.11. The requirements for keeping training records should be consistent with regulatory requirements and recommendations, and they should be specified in the radiation protection programme.

Local rules and supervision

4.12. Local rules that describe the procedures for carrying out radiography work should be developed and written in a language known by the people who will follow them. These local rules should cover all procedures associated with radiography work where there is the potential for radiation exposure, such as routine operations, source exchanges and transport (see Sections 10 and 11). The local rules are an important tool in the restriction of radiation doses. They should include sufficient information and guidance to allow radiographers and other workers to carry out their duties safely and in compliance with regulatory requirements.

4.13. Management should ensure that all relevant persons have read and understood the local rules. A copy should be provided to all radiographers and other relevant persons, and additional copies should be available in the work area. In smaller organizations with a limited amount of radiography work, it may be appropriate to have one set of local rules covering all procedures.

4.14. In larger organizations, it might be appropriate to have several sets of specific local rules. Such sets might comprise procedures for carrying out radiography work in shielded radiography enclosures[3], procedures for carrying out site radiography work and procedures for exchanging gamma sources. Some client organizations might also require specific local rules to be drawn up to cover radiography work on their premises.

4.15. The operating organization should appoint at least one employee as a radiation protection officer to oversee the day to day implementation of the radiation protection programme and to carry out duties as required by the programme. Details of the duties of the radiation protection officer are given in Section 2.

[3] 'Shielded radiography enclosures' are hereinafter referred to as 'shielded enclosures'.

Designation of controlled areas or supervised areas

4.16. The radiation protection programme should describe how controlled areas[4] and supervised areas[5] are to be designated for the conduct of industrial radiography work. Controlled areas should be used to restrict exposures in industrial radiography work. Supervised areas should sometimes be used, particularly around fixed radiography facilities. The designation of such areas should be based on the safety assessment and the measured dose rates. Guidance should be provided on setting up controlled areas, especially for site radiography work (see Sections 10 and 11).

Programme of workplace monitoring

4.17. The radiation protection programme should describe the programme for the selection, calibration, maintenance and testing of equipment to measure radiation dose rates. A programme for the routine use of the monitoring equipment should be specified. The programme should provide information on the necessary frequency of dose rate measurements around fixed facilities, the monitoring procedures to be followed in carrying out site radiography work, the details to be recorded and the length of time for which the records should be kept.

4.18. The radiation protection programme should specify that an adequate number of suitable radiation monitors will be made available to the radiographers. For site radiography work, the minimum number of radiation monitors is one operational dose rate meter for each source in use, although one dose rate meter per radiographer is preferable (see Section 7).

4.19. The radiation protection programme should include dose rate reference levels. These reference levels are the maximum dose rates that are acceptable during the performance of specific tasks, such as at controlled area barriers during site radiography work and at the operator's position. Such dose rate reference levels should be consistent with regulatory requirements and guidance.

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[4] A controlled area is a defined area in which specific protection measures and safety provisions are or could be required for: (a) controlling normal exposures or preventing the spread of contamination during normal working conditions; and (b) preventing or limiting the extent of potential exposures.

[5] A supervised area is a defined area not designated a controlled area but for which occupational exposure conditions are kept under review, even though no specific protective measures or safety provisions are normally needed.

Arrangements for individual dose monitoring

4.20. The radiation protection programme should specify the types of dosimeters to be used by workers, the period of wearing, and arrangements for the assessment of dosimeters and dose record keeping. The radiation protection programme should also specify that the dosimetry service provider should be appropriately approved or accredited. The radiation protection officer should review the dose records periodically to identify doses that may be higher than usual (see Section 6), and to review whether doses are as low as reasonably achievable.

Health surveillance programme

4.21. The radiation protection programme should include details of a programme for periodic health surveillance of radiographers and other employees as appropriate. This should include a requirement to assess the initial and continuing fitness of workers for their intended tasks. A qualified expert and/or an appropriately qualified medical doctor should be consulted in the drawing up of the programme for health surveillance, and it should be consistent with regulatory requirements.

Emergency preparedness plans

4.22. The radiation protection programme should include emergency preparedness and response plans that are to be implemented in the event of an emergency. Plans should be provided to cover all reasonably foreseeable emergencies. Guidance on emergency preparedness is provided in Section 13.

Periodic reviews and audits of the performance of the radiation protection programme

4.23. As an integral part of the operating organization's management system, the radiation protection programme and its implementation should be assessed on a regular basis. This periodic review should identify problems to be addressed and any modifications that could improve the effectiveness of the radiation protection programme.

4.24. A key part of this periodic review process is a routine series of workplace audits, including the designation and qualifications of the persons who will conduct them, their frequency, the expectations of the audit team, and the reporting of results and their follow-up.

Quality assurance and process improvement

4.25. Industrial radiography work and its associated activities should be carried out in accordance with the 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 brought to the attention of the management and are promptly remedied.

4.26. The management should also ensure that the correct operational procedures are being followed, and that the quality assurance programme 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 content and details of the quality assurance programme.

4.27. The management system should include a mechanism for the collection and feedback of lessons learned from emergencies and incidents (including those reported both within the organization and in external reports), and how these lessons can be used to enhance safety.

RECORD OF THE SAFETY ASSESSMENT

4.28. The main basis for the radiation protection programme is the safety assessment, which identifies the nature and extent of the radiation hazards that may be encountered in the course of industrial radiography operations. The report of the safety assessment should form an integral part of the documentation of the radiation protection programme.

RADIATION SAFETY COMMITTEE

4.29. In medium to large sized radiography companies, a radiation safety committee should be established for the purpose of regularly reviewing the performance of the radiation protection programme. This committee may be dedicated to radiation safety or it may have other (conventional) safety related responsibilities. The committee should include the senior manager(s) responsible for radiation safety, the radiation protection officer(s), radiographer(s) and representatives of the workforce. The responsibilities of the radiation safety committee should include, but not be limited to:

(a) Regular reviews of all aspects of the radiation protection programme;
(b) Reviews of occupational radiation doses and any accident reports prepared by the radiation protection officer;
(c) Making recommendations for improvements in the radiation protection programme;
(d) Provision of guidance and direction on the performance of the radiation protection officer's duties;
(e) Preparation and dissemination of regular reports to all staff about relevant radiation safety issues.

5. TRAINING AND QUALIFICATION

GENERAL

5.1. Persons performing industrial radiography work are responsible for ensuring that their work is carried out safely and in compliance with all relevant regulations and safety standards. Operating organizations should, therefore, ensure that radiography work is carried out only by radiographers and assistants who are qualified or certified, and who are competent and trained in protection and safety.

5.2. There are internationally recognized schemes for the training and qualification of radiographers utilizing techniques of non-destructive testing. Some of these schemes may include only a limited amount of training in radiation safety. In this case, they should be supplemented with additional training specifically in protection and safety. Such additional training may be provided by specialized training organizations rather than by the operating organization.

DESIGN OF A TRAINING PROGRAMME

5.3. Training courses in protection and safety may be provided by a range of training providers, including colleges, universities, radiation protection institutions and training consultants [11, 12]. Some States also have access to a centralized training facility, which may be a national or regional training centre that is supported by the IAEA. These training centres may offer training courses in radiation safety that are specially developed for industrial radiographers.

5.4. Radiography personnel should be classified into different levels of competence on the basis of their training and experience. In some States, for example, these levels are designated as assistant radiographer (i.e. trainee) and radiographer (i.e. a person who is fully qualified), or as Level 1 radiographer and Level 2 radiographer. Some States also have Level 3 radiographers, who can carry out training, set examinations and carry out assessments of other radiographers.

5.5. Programmes should be established for the different levels of training corresponding to the responsibilities of the radiographer. The training programme should establish the criteria for passing written and practical examinations, 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. Further details about training are given in the following.

STRUCTURE AND CONTENT OF THE TRAINING COURSE

5.6. Each training course should be structured around specific aims and objectives and should be customized to the needs of the target audience. Information on the structure and content of training courses in radiation protection for industrial radiographers can be found in Refs [11, 12]. A summary of the essential elements for basic training in radiation safety for industrial radiographers is given in the following.

Fundamental concepts and measurements

— Basic radiation concepts;
— Radiation quantities and units;
— Radiation detecting instruments;
— Biological effects of radiation.

Principles of radiation protection

— System of radiation protection (justification, optimization and dose limitation);
— Regulatory requirements;
— Designation of controlled areas and of supervised areas;
— Dose limits and investigation levels.

Practical radiation protection

— Source outputs;
— Effects of time, distance and shielding;
— Individual monitoring;
— Working practices to limit doses and maintain them as low as reasonably achievable;
— Storage of radioactive sources;
— Correct operation and maintenance of radiography equipment;
— Radiation protection programme;
— Local rules;
— Emergency plans;
— Management of radiation protection;
— Transport of radioactive sources;
— End-of-life considerations for sources following decay;
— Accidents and other incidents involving radiography sources, their consequences and lessons learned;
— Emergency preparedness and response.

5.7. The training should provide practical exercises, including the rehearsal of emergency plans (see Section 13) such as plans for retrieving a jammed source. However, radioactive sources should never be used in such rehearsals. Training devices are available that use radiofrequency transmissions to simulate radioactive sources and can be detected by using radiofrequency detectors that are specially designed to look like a dose rate meter. An alternative is to use 'dummy' sources that look like a radiography source 'pigtail' but are not radioactive.

REFRESHER TRAINING

5.8. Radiography personnel should ensure that their knowledge and skills are kept up to date through a programme of refresher training. Such training should include a review of the fundamentals of protection and safety, and information on changes to equipment, policies and procedures, and possible changes in regulatory requirements.

5.9. The frequency of refresher training should be consistent with regulatory requirements. Refresher training is typically given at intervals of less than two years but not exceeding five years. Such training could be combined with other refresher training on radiography techniques, and it may be certified. However,

changes in regulations or notifications of safety issues should be disseminated as written instructions as soon as practicable, and then followed up by inclusion in refresher training.

6. INDIVIDUAL MONITORING OF WORKERS

INDIVIDUAL DOSE ASSESSMENT

6.1. Operating organizations should ensure that radiation doses to radiography personnel are assessed on a regular basis to ensure that doses are kept as low as reasonably achievable and are below the dose limits. An assessment of the doses could also highlight good or bad working practices, faulty equipment, or the degradation of shielding or engineered safety systems.

6.2. Operating organizations should make arrangements with a dosimetry service for the provision of suitable dosimeters to workers for the purpose of formal record keeping of doses. The dosimeters should be worn by all radiographers, assistants and any other workers who may regularly be required to enter controlled areas; and also supervised areas where this is required by national regulations. Dosimeters can also provide useful data in the event of an emergency or incident.

6.3. Thermoluminescent dosimeters and film dosimeters are commonly used. Both types incorporate a passive element to record radiation exposure which is subsequently processed by a specialized dosimetry laboratory to assess the dose. Another type of dosimeter is the electronic personal dosimeter, which utilizes a solid state detector to give an immediate readout of radiation dose (and sometimes also dose rate). In some States, and in some situations, the electronic personal dosimeter is an approved replacement for the thermoluminescent dosimeter or film dosimeter.

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

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

(a) Dosimeters should be worn by radiography personnel at all times when carrying out any work with radiation. Additional dosimeters are likely to be necessary if radiography is performed at facilities where there is exposure to additional sources of radiation, such as at nuclear power plants.
(b) Dosimeters should be worn in accordance with recommendations from the dosimetry service provider.
(c) For thermoluminescent dosimeters 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) Dosimeters can be sensitive, and care should be taken to avoid damaging the measuring element of the dosimeter (e.g., dosimeters can be damaged by water, high temperature, high pressure and physical impact).
(f) Dosimeters should not be exposed to radiation when not being worn by the radiographer (the dosimeter should be stored in an area away from radiation sources).
(g) Thermoluminescent dosimeters and film dosimeters should be promptly processed by the dosimetry service at the end of the period of wear.
(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 not being worn.

PERSONAL ALARM MONITORS

6.6. Personal alarm monitors are small electronic radiation detectors that emit a warning signal when a preset dose and/or dose rate is exceeded. Such monitors may be dedicated devices, or in the case of an electronic personal dosimeter, a warning signal is usually built in to the ‘legal’ dosimeter. The warning signal is normally an audible alarm, although this may be supplemented by a vibration or a visible signal (which may be useful if the ambient noise level is high and/or if ear protectors or other safety equipment is being worn).

6.7. Such additional information can be useful in keeping radiation doses as low as reasonably achievable. It may also help to alert radiographers to problems, hence preventing or mitigating emergencies and incidents. Operating organizations should therefore provide personal alarm monitors to all radiographers and assistants, especially if gamma radiography work is to be carried out.

6.8. Important considerations in relation to the use of personal alarm monitors include the following:

(a) Personal alarm monitors should be used only to supplement, but not to replace, thermoluminescent dosimeters or film dosimeters.
(b) Personal alarm monitors should not be used as a replacement for dose rate survey meters (see para. 6.14).
(c) Personal alarm monitors should be tested periodically in accordance with national recommendations and/or guidance from the manufacturer.

6.9. Some personal alarm monitors also give a numerical readout of dose and/or dose rate, in addition to giving an audible or visible alarm.

DIRECT READING DOSIMETERS

6.10. Direct reading dosimeters give an instantaneous reading of the dose received. These can be a very useful tool in restricting exposures in industrial radiography work, especially for specific tasks. Direct reading dosimeters should be provided by the operating organization, and they should be tested in accordance with the manufacturer's instructions.

6.11. The quartz fibre electroscope, which is a device that shows accumulated dose via the deflection of an electrically charged fibre on a scale, is a simple type of direct reading dosimeter. Quartz fibre electroscopes have been used widely for many years, but they have now been largely superseded by more modern electronic direct reading dosimeters.

6.12. Electronic direct reading dosimeters may incorporate an audible and/or visible alarm feature, to warn if a preset dose or dose rate has been exceeded. This also enables them to be used as personal alarm monitors.

6.13. Some specific electronic direct reading dosimeters (e.g. electronic personal dosimeters) can also be used to replace thermoluminescent dosimeters or film dosimeters as the main 'recording keeping' dosimeter for legal purposes, although this depends on regulatory requirements.

6.14. As with personal alarm monitors, electronic personal dosimeters are designed and calibrated to measure personal doses rather than workplace dose rates, and so they should not be used as a replacement for workplace radiation survey meters.

RECORD KEEPING

6.15. The operating organization should keep records of doses received by radiographers and any other persons who regularly enter controlled areas, and also for supervised areas where so required by national regulations. These records should contain details of the doses recorded by the dosimeters worn by workers. They should clearly identify any doses received in incidents or in following emergency procedures, as distinct from those received during routine work. These dose records are usually concerned with the doses recorded on the worker's primary individual dosimeter, and are not usually also used to record measured doses derived from additional devices such as quartz fibre electroscopes and direct reading dosimeters.

6.16. Radiographers and other workers subject to individual monitoring should be informed of their personal doses. The operating organization should also make arrangements for the records to be made available to the radiation protection officer, and also when required to the physician responsible for the health surveillance programme and to the regulatory body.

6.17. When a worker changes or leaves employment, the operating organization should provide the worker and the new employer with a summary of the worker's dose records. When a worker stops carrying out radiography work, or leaves the organization and does not commence radiography work with another employer, the operating organization should make arrangements for the retention of the worker's dose records, either by the operating organization itself or by another body as specified in national regulations.

6.18. Regulatory requirements may specify a duration over which dose records for each worker are to be kept; for example, until a worker attains or would have attained the age of 75 years, and for not less than 30 years after termination of the work with radiation. In satisfying the record keeping requirements, the operating organization should ensure that appropriate confidentiality of the records is maintained.

INVESTIGATION OF DOSES

6.19. The operating organization should carry out an investigation if a dose to a radiographer, other worker or member of the public exceeds any dose limit or investigation level specified by the regulatory body or operating organization. The investigation should focus on the causes of the incident that resulted in the overexposure, and on any failures in procedures or safety systems that contributed to the incident. The investigation report should identify any improvements to procedures or facilities to optimize protection and to reduce the likelihood of a similar event occurring, and/or to mitigate the consequences.

HEALTH SURVEILLANCE

6.20. The operating organization should make arrangements for the health surveillance of relevant employees in accordance with regulatory requirements. Initial health surveillance should be carried out to assess whether a worker has an adequate level of fitness for the intended tasks and also to assess the worker's psychological suitability for work with radiation sources. Periodic health assessments should also be made to ensure that the worker's health remains satisfactory.

7. WORKPLACE MONITORING

PROGRAMME OF MONITORING

7.1. The operating organization should establish a programme of monitoring of radiation levels in and around the workplace [13]. The adequacy of the arrangements in place for protection in radiography work should be assessed in the programme, which should include measurements of radiation levels at the following positions:

(a) For radiography in shielded enclosures:
   (i) Around the walls and doors (and other openings) of the enclosure under a range of operating conditions, to ensure that an adequate level of shielding is maintained;

(ii) At the entrance to the enclosure after completion of each gamma radiography exposure, to confirm that the gamma source has been satisfactorily returned to the exposure device or that X ray emission has stopped;

(iii) Around the gamma source store, to ensure that an adequate level of shielding is provided.

(b) For site radiography work:

(i) Around barriers during a test exposure (or first exposure, depending on the circumstances) to confirm that the barriers are correctly positioned;

(ii) At the operator position during wind-out of a gamma source or when an X ray generator is energized, to confirm that radiation levels are not unacceptable;

(iii) Around the barriers during routine exposures, to confirm that dose rates remain below any values specified in national regulations or guidance or by the operating organization;

(iv) At the operator position during wind-in of a gamma source or termination of exposure of an X ray generator;

(v) Around the exposure device after each exposure, to ensure that the source has been fully returned to the shielded position;

(vi) Around any source store used on-site, to ensure that an adequate level of shielding is provided;

(vii) Around the site on completion of the radiography work, to confirm that no gamma sources have been left on the site;

(viii) Around vehicles used to transport gamma sources prior to departure to and from the site.

7.2. The 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. Reference levels for each measurement location should be given, and the actions to be taken if these values are exceeded should be described. Records of the workplace monitoring programme should be made available to appropriate persons, including workers and the regulatory body.

SELECTION, MAINTENANCE AND CALIBRATION OF SURVEY METERS

7.3. Operating organizations should ensure that a sufficient number of suitable dose rate monitors are made available to the radiographers. While many types of monitors are suitable for measuring gamma radiation levels, some may not be

suitable for accurately measuring low energy X rays, which could result in a significant underestimation of the true dose rate. Information and guidance on the suitability of monitors should be obtained from manufacturers' literature and qualified experts.

7.4. The operating organization should arrange for radiation monitors to be formally tested or calibrated at periodic intervals by a specialized testing laboratory. A number of operating characteristics of the radiation monitor should be assessed in these tests or in the calibration. These operating characteristics include the response to known dose rates at specific energies, the linearity and the behaviour of the monitor at very high dose rates. The frequency and the type of tests or calibration, together with appropriate records, should comply with any requirements specified either in national legislation and/or regulations or by the regulatory body. They should also follow any recommendations of the manufacturer.

7.5. Routine operational checks of the radiation monitors should be carried out by the radiographers and the radiation protection officer. These may include physical checks of whether the monitor is damaged, battery checks and zeroing of the scale. The response of the monitor to radiation should be checked before use in accordance with the regulatory requirements. This may be done, for example, by using a low activity test source, or by placing the monitor close to the surface of an exposure device when the source is in its shielded position. Some regulatory bodies may require that such checks be done in accordance with formal procedures and the results recorded.

7.6. Account should also be taken of the environmental conditions in which the monitors are to be used. Some monitors are unsuitable for use in very wet or very hot locations, and some are not robust enough to withstand heavy use on-site. On some industrial sites where site radiography work is carried out, special types of radiation monitors may have to be used. For example, in some chemical factories, radiographers may have to use radiation monitors that minimize the likelihood of accidental ignition of flammable fumes or vapours in areas of the plant (these are often called intrinsically safe monitors).

7.7. Some radiation monitors are affected by radiofrequency transmissions. If radiography is to be carried out close to radiofrequency generating equipment, then the use of specially designed radiofrequency shielded radiation monitors should be considered. Account should also be taken of noise where these devices are being used. Audible warnings should be loud enough to be heard and/or they should be supplemented by vibration or visible signals.

8. CONTROL OF RADIOACTIVE SOURCES

8.1. Radioactive sources used for industrial radiography can, and have, caused serious accidents [14–18]. Gamma sources used in industrial radiography are generally considered to be Category 2 sources under the IAEA Categorization of Radioactive Sources [19] (see the Appendix). Operating organizations should ensure that gamma radiography sources are kept under proper control. This should apply from the time they are first acquired until they are finally returned to their original supplier or safely dealt with at the end of their lifetime. Internationally endorsed recommendations to States on the safety and security of Category 1, 2 and 3 sources are given in the Code of Conduct on the Safety and Security of Radioactive Sources [20].

8.2. In relation to the security of radioactive sources, the BSS (Ref. [2], para. 2.34) require that:

> "Sources shall be kept secure so as to prevent theft or damage and to prevent any unauthorized legal person from carrying out any of the actions specified in the General Obligations for practices of the [Basic Safety] Standards (see paras 2.7–2.9), by ensuring that:
>
> "(a) control of a source not be relinquished without compliance with all relevant requirements specified in the registration or licence and without immediate communication to the [regulatory authority], and when applicable to the relevant Sponsoring Organization, of information regarding any decontrolled, lost, stolen or missing source;
> "(b) a source not be transferred unless the receiver possesses a valid authorization; and
> "(c) a periodic inventory of movable sources be conducted at appropriate intervals to confirm that they are in their assigned locations and are secure."

8.3. Operating organizations should ensure that they obtain radioactive sources only from authorized suppliers, and that disused sources are returned to the original supplier or transferred to another authorized body. 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 [20] and its supplementary guidance on import and export controls [21].

8.4. Operating organizations are required to conduct a periodic inventory of sources, to confirm that they are in their assigned locations and are secure [2]. Sources should be removed from a source store or moved to another location only by authorized and trained radiographers. The radiographers should log their name, the date and time, and the exact 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 radioactive sources are where they are supposed to be. Exposure devices that incorporate depleted uranium shielding should be included in the accountancy procedures.

8.5. Any suspected loss of control over a radioactive source should be promptly investigated by the operating organization and notified to the regulatory body (and any other authority considered to be relevant) within 24 hours or as otherwise specified in regulatory requirements.

8.6. Guidance on the security of radioactive sources and the prevention of malicious acts has been issued by the IAEA [22].

9. SAFETY OF INDUSTRIAL RADIOGRAPHY SOURCES AND EXPOSURE DEVICES

GENERAL

9.1. A wide variety and range of types of radiation sources, exposure devices and ancillary equipment are commercially available for carrying out industrial radiography work. Equipment used for radiography should be obtained from an authorized manufacturer with an established management system such as ISO 9001 [9] or equivalent national standard, to ensure that the design safety features are reproduced consistently. The operating organization should ensure that information on the safe use of the equipment is provided by the supplier. The operating organization should also ensure that this information is made available to users in a language that they know.

9.2. Operating organizations should ensure that equipment used for industrial radiography purposes is not modified without prior assessment of the implications of the modification for the original design and the safety assessment. The prior assessment should be reviewed by a qualified expert or by the supplier,

and it should be discussed with the regulatory body, to determine whether additional authorization or approval is required.

9.3. Descriptive information on the various types of radiography systems is provided in Annex II. Guidance on safety issues in relation to equipment is given in the following.

GAMMA RADIOGRAPHY SOURCES AND EXPOSURE DEVICES

9.4. Gamma radiography equipment utilizes a high activity sealed source housed in a shielded exposure device. The source remains in the shielded exposure device when not in use. The source is exposed by remotely moving it from the shielded exposure device (e.g. by using push–pull wires) directly into an attached guide tube. It remains in the guide tube for the desired exposure time, after which it is wound back into the shielded exposure device.

9.5. Equipment used for gamma radiography typically consists of several components such as a remote wind-out mechanism (often called a 'crank'), connected to the radiography source (often called a 'pigtail') inside a shielded exposure device, which is connected to the guide tube. 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.

Sealed radioactive sources

9.6. When carrying out gamma radiography work, operators should use only sealed sources that meet international or equivalent national standards, as described below. These standards set out the normal operating conditions that a sealed source should withstand. Only sealed sources that meet the following criteria should be used for industrial radiography purposes. Sources should be:

(a) Certified as meeting the requirements for 'special form' radioactive material as established in the IAEA Transport Regulations [23];
(b) Designed, manufactured and tested to meet the requirements of the appropriate ISO standard [24] or an equivalent national standard;
(c) Leak tested in accordance with the appropriate ISO standard [25] or an equivalent national standard and with a valid leak test certificate that is traceable to each individual source.

9.7. Sealed sources used for industrial radiography purposes are normally part of a source assembly (the 'pigtail') that is connected to the drive cable in source projection type systems. Source assemblies should be:

(a) Designed, manufactured and tested to ensure that they meet the requirements of the appropriate ISO Standard [26] or an equivalent national standard;
(b) Compatible with the exposure container, ancillary equipment (such as guide tubes) and any source changer with which they are used;
(c) Marked in accordance with ISO 361 [27] or an equivalent national standard, or, as a minimum, marked with the radiation symbol (trefoil) and the legend 'RADIOACTIVE'. They should also be durably marked with the manufacturer's serial number.

9.8. The source assembly should be compatible with the specific exposure device in which it is intended to be used. It should also have undergone proven testing in accordance with ISO 3999 [26] or an equivalent national standard.

9.9. Some manufacturers give a recommended working life for a sealed source. The recommended working life is based on a number of factors, including the half-life of the source and the construction of the source encapsulation. It is an indication of the period of time over which the source should retain its integrity. The manufacturers concerned recommend that work with a source stop when the age of the source reaches the recommended working life.

9.10. Alternatively, a physical assessment of the condition of the source by a suitably experienced body or expert may be carried out to support its continued use. The regulatory body may recommend certain tests for continued use of a source after the source reaches its recommended working life, such as an increased frequency of leak tests or assessment by a qualified expert with access to the appropriate facilities.

Exposure devices

Projection type exposure devices

9.11. The sealed source is stored and used within a specifically designed exposure device that incorporates safety devices and features designed to reduce the risk of human error or equipment malfunction. A description of the various types of exposure device is provided in Annex II.

9.12. The exposure device should comply with the requirements of ISO 3999 [26], an equivalent standard or national requirements. Meeting this standard ensures that a minimum safety standard has been met and that the device and source combination is suitable for use for industrial radiography purposes.

9.13. Most exposure devices also meet the requirements for a Type B(U) transport package as prescribed in the IAEA Transport Regulations [23]. Further guidance on safe transport of sources is given in Section 12.

Other types of exposure device

9.14. There are some types of exposure device still in use that do not meet ISO 3999 [26], owing to either old design or unique or unusual applications. Operating organizations should ensure that such devices are not further used until a safety assessment has been performed to determine whether any additional safety precautions should be taken.

9.15. Such devices should also have a specific authorization where necessary from the regulatory body prior to use. Some examples of this include air actuated devices that expose the source by projecting it out into a guide tube using compressed air (with no control cable connected to the source). Although this results in low doses to the operator, it is possible to project the source out of the exposure device even if the guide tube is not in place. Such systems can also be prone to problems associated with the return of the source to the shielded position.

9.16. Another type of exposure system that has been used historically is the 'torch' system. The use of such equipment is not justified, as radiographers using this type of equipment were subjected to unacceptably high radiation levels, but a short description is given here for completeness. In a torch system, the radioactive source was mounted at the end of a short rod that was stored inside an exposure device. To expose the source, it was manually removed from its exposure device (on the end of the rod or torch) and inserted into a collimator attached to the workpiece.

Marking and labelling

9.17. Each exposure device should be permanently and clearly labelled with the following details:

(a) The international ionizing radiation symbol (trefoil) [27];
(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 of use;
(c) The chemical symbol(s) and mass number of the radionuclide(s) for which the exposure device is suitable (e.g. "^{192}Ir" or "^{60}Co");
(d) The maximum source activity permitted in the exposure device, quoted for each radionuclide for which the exposure device is suitable;
(e) The international standard (ISO 3999 [26]) or equivalent national standard to which the exposure device and its accessories conform;
(f) The name of the manufacturer, the model number and the serial number of the exposure device;
(g) The mass of the depleted uranium shielding, where relevant, or the indication "Contains depleted uranium";
(h) The operator's name, address and telephone number.

9.18. In addition, the exposure device should display a durable fireproof label or tag bearing information about the radioactive source that it currently contains, including:

— The chemical symbol and mass number of the radionuclide;
— The activity on a stated date;
— The identification number of the sealed source;
— The identity of the source manufacturer.

Second-hand equipment

9.19. Operating organizations that acquire used or second-hand radiography equipment should ensure that the equipment, together with any ancillary equipment, meets current international standards [26] or an equivalent national standard. This should be accomplished by having an assessment performed by the manufacturer or another competent body.

Depleted uranium shielding

9.20. The shielding of many exposure devices (and some collimators) incorporates depleted uranium as this is denser than lead. This enables exposure devices to be made physically smaller than would be possible with lead shielding alone. It also allows the package to meet the requirements for Type B(U) packages under the Transport Regulations [23] where relevant. Depleted uranium is radioactive, which means that even when 'empty' (i.e. not containing a

radiography source) exposure devices of this type should be stored safely, and they should be subject to accountancy procedures.

9.21. Operators should establish which, if any, of their exposure devices and collimators incorporate depleted uranium. Operators should also ensure that any exposure devices and collimators that do incorporate depleted uranium are durably marked as such. Some regulatory bodies may also require a separate authorization for such exposure devices and collimators. Their eventual disposal should be in a manner authorized by the regulatory body.

Ancillary equipment

9.22. Ancillary equipment used with an exposure device includes the control housings, guide tubes and collimators. The minimum performance standards for the ancillary equipment are given in ISO 3999 [26]. The equipment should meet the requirements of this standard or an equivalent national standard.

9.23. Each model of exposure device will have its own specific ancillary equipment. The ancillary equipment should be compatible with the specific exposure device and source assembly with which it is intended to be used, to avoid incidents. Any uncertainties about compatibility should be checked with the relevant manufacturer(s).

9.24. Ancillary equipment such as control cables and guide tubes are available, to maximize the distance between the radiographer and the source. Typical lengths are 7–15 m for control cables and 2–6.5 m for guide tubes. The devices should not be operated with control cables and guide tubes that are longer than the manufacturer's recommendations.

Collimators

9.25. Collimators are used to reduce the radiation beam in some directions. They should be used whenever possible, to reduce radiation levels and subsequent doses. Collimators are usually manufactured from lead, tungsten or depleted uranium, and they may provide either panoramic or directional beams. The operating organization should ensure that the collimators are compatible with the source assembly, so as not to cause the source to jam.

Source changers and storage containers

9.26. Source changers should be used for the safe exchange of old and new industrial radiography sources between the operator's exposure device and the source changer (normally the shipment container) used by the source supplier (which should normally be returned to the supplier after the exchange of a source). Storage containers should allow for the safe storage of sealed sources when not in use, and should prevent unauthorized access.

9.27. Although there are no specific standards for source changers or storage containers, when possible, they should meet the applicable sections of ISO 3999 [26] or equivalent national standards for dose levels and labelling. Source changers should incorporate a system for ensuring that the source is not accidentally withdrawn from the source changer when connecting or disconnecting. They 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.

9.28. Operators should ensure that source changers that incorporate depleted uranium are treated as radioactive sources even when 'empty' (i.e. when not containing a radiography source), and that they are disposed of only in a manner authorized by the regulatory body.

Storage of radioactive sources

9.29. On-site storage facilities for sources and exposure devices should consist of a lockable room or a purpose-built store that provides an adequate level of protection and safety. The room or store should be designated as a controlled area or supervised area, where appropriate, and should be:

(a) Resistant to fire, to minimize the potential for loss of shielding and containment in the event of a fire in the vicinity;
(b) Located at a remote distance from any corrosion and explosion hazards;
(c) Made of materials that provide sufficient shielding to reduce dose rates outside the room or store to below the relevant levels specified by the regulatory body.

The door to the storage facility should be kept locked and the keys should be held only by authorized personnel. A notice incorporating the radiation symbol (trefoil) should be displayed on the door.

Inspection and maintenance

General good practice

9.30. To ensure continued good operation, gamma radiography equipment (including all ancillary equipment) should be subject to routine inspection and periodic maintenance.

9.31. Periodic maintenance should be performed only by the manufacturer or by specially trained personnel in accordance with the manufacturer's instructions. Any replacement parts should be obtained only from the manufacturer, in order to comply with the original safety specifications. Any modifications should be subject to approval by the manufacturer or the regulatory body if required.

9.32. General good practices should include keeping equipment clean so that it functions properly. Mud and dirt should be cleaned off after use of the source, as it could hinder the movement of the source.

Routine inspection

9.33. Radiographers should carry out routine inspection before the start of radiography work, to detect conditions that could lead to an incident if left uncorrected. Some typical checks should include:

(a) Inspection of the exposure device to ensure that:
  (i) Fittings and fasteners are tight.
  (ii) The locking mechanism functions properly.
  (iii) Radiation levels are normal.
  (iv) The connections of the guide tube and the control mechanism are secure.
  (v) The source assembly connection to the drive cable is verified to be secure using a wear gauge, such as a 'go/no-go' type check gauge supplied by the manufacturer to check for excessive wear.
(b) Inspection of the remote controls to ensure that:
  (i) Fittings are tight.
  (ii) There are no indications of crushing, kinks or dents.
  (iii) The drive cable can move freely.

(c) Inspection of the source guide tubes to ensure that:
  (i) Fittings are tight.
  (ii) There are no indications of crushing, kinks or dents.
  (iii) Source tips are not worn through.

9.34. Radiographers should inspect any additional ancillary equipment being used (such as magnetic stands, vice grip clamps and collimator attachments) for the following:

— Freedom of movement;
— Good working condition;
— Appropriateness for use.

When performing a source exchange, radiographers should perform the following pre-operational checks to ensure that:

— Lock assemblies function properly.
— Guide tube and transfer tube connections are secure.
— There are no obstructions in the guide tubes or transfer tubes.

Maintenance programme

9.35. The operating organization should set up a programme of maintenance of all the equipment used for gamma radiography. The programme should indicate that only the supplier or specially trained operators should perform this maintenance. The maintenance should be performed at the required intervals, with account taken of any use of equipment in severe environments, such as in the presence of sand, dirt or water.

9.36. The maintenance consists of the complete disassembly of the equipment and a detailed inspection of all the components. Where required, worn or damaged parts should be replaced and suitable lubricant should be applied. Records should be kept of all maintenance, including the replacement of parts.

X RAY GENERATORS

9.37. The most common type of X ray generator used for industrial radiography is the conventional X ray tube, although, in a few specialized applications, linear accelerators and cyclotrons are also used. The following recommendations apply

to X ray tubes, although a similar standard of safety should be applied to linear accelerators and cyclotrons.

9.38. X ray generators are used for performing panoramic (radial beam) exposures and directional exposures. The X ray tube is connected by cable to the control panel, which provides the means for the preselection and indication of operating parameters. The dose to the radiographer can be affected by the cable length, operating parameters (kilovoltage and current) and the local shielding around the device. Operating organizations should use only X ray generators that comply with the minimum standards set out in the following.

Electrical safety

9.39. Electrical safety contributes indirectly to radiation safety, since electrical faults in X ray generators can result in serious accidents, some with radiological consequences. X ray generators should conform to national and international electrical safety requirements [28]. In particular, metallic items including casings, interconnecting cables, power supply units (transformers and generators), control equipment, tube assemblies, warning signal devices and other safety devices should be electrically bonded together ('earth bonding') and connected to earth (grounded). Advice on electrical matters should be provided, and inspection and testing should be performed by a qualified electrical engineer or by a specialized service engineer.

Cable length

9.40. Where radiography cannot be carried out in a shielded enclosure, cable lengths should typically be not less than 20 m for X ray generators up to 300 kV and longer for higher energy equipment.

Collimators and beam filters

9.41. X ray generators used for directional radiography should, wherever practicable, be fitted with collimators (sometimes called cones or diaphragms), to limit the beam size to the minimum compatible with the radiographic technique. The equipment should incorporate beam filters, to enable the filtration to be matched to the work being undertaken.

Control panel

9.42. The control panel should include the following features:

(a) A label incorporating the radiation symbol (trefoil), a legend indicating that X rays are emitted when the equipment is operating and a warning label (in a language known locally) prohibiting unauthorized use.
(b) A key switch to prevent unauthorized use. The key should be removable only when the switch is in the 'off' or 'standby' position (i.e. it should not be possible to lock the system in the 'on' condition). Key positions should be clearly marked.
(c) A labelled warning light ('fail-to-safe') that indicates when the equipment is enabled (i.e. ready to emit X rays).
(d) A separate labelled warning light (fail-to-safe) that indicates when the equipment is actually emitting X rays.
(e) A timer that controls the exposure duration, or an 'on' switch that requires continuous pressure by the radiographer to maintain the generation of X rays.
(f) Indicators that show the kilovolts (kV) and the current in milliamperes (mA) when the X ray beam is 'on'.
(g) A clearly labelled means of immediately terminating the generation of radiation.

X ray tube head

9.43. The X ray tube head should, wherever practicable, be supported in a suitable stand or clamped into position, to prevent inadvertent movement. Leakage radiation (i.e. radiation that passes through the sides of the device rather than forward from the beam aperture) should be restricted by good design and construction. Its level should be specified by the manufacturer of the device.

9.44. The penetrating power of leakage radiation depends on the kilovoltage and is particularly significant above 500 kV. Data on the maximum dose rates due to leakage radiation at the surface of the device and at 1 m from the X ray target should be documented by the manufacturer. Typical maximum dose rate values for leakage radiation from commercial X ray tubes are up to 100 $\mu Sv \cdot h^{-1}$ at 1 m from the target.

Flash X ray units

9.45. Some X ray generators emit very short pulses of X ray radiation, and the exposure duration is set in terms of the number of pulses required for the exposure. Such flash X ray units are often small, portable, battery driven units used for the radiography of items of low density or very low wall thickness. Large flash X ray units are sometimes used in shielded facilities where a high output

and extremely short exposure time are required. The same precautions that are used for regular X ray equipment should be used, together with any additional safety precautions as determined by the safety assessment.

9.46. It should be noted that most dose rate meters are unsuitable for the measurement of dose rates near flash X ray units, owing to the extremely short pulse time of the units and the relatively slow response time of the meters. Instead, suitable integrating dosimeters should be used.

Inspection and maintenance of X ray equipment

General good practice

9.47. To ensure continued good operation, X ray equipment (including all ancillary equipment) should be subject to both routine checks by the operating organization and formal inspections and maintenance by the manufacturer or a qualified expert. Any replacement parts should be obtained only from the manufacturer, in order to comply with the original safety specifications.

9.48. Periodic tasks that can be carried out by the operating organization should include:

(a) Checks for electrical safety, including earth grounding and tests of electrical insulation of cables;
(b) Cleaning or replacement of any filters in cooling systems;
(c) Checks for X ray leakage from the tube;
(d) Checks to ensure that all cables are in good condition, with no fraying or bare wires;
(e) Other routine checks and maintenance as recommended by the manufacturer;
(f) Tests on all interlocks and emergency cut-out switches;
(g) Tests on all permanently installed radiation detectors inside shielded enclosures, and ensuring that this is done while no one is inside the enclosure.

Routine inspection

9.49. The routine inspection should be performed at the start of the work. This is carried out to detect conditions that could lead to an incident if left uncorrected. Inspection should typically include checks of the following:

— There is no visible damage to the equipment.
— Cables have no cuts, breaks, kinks or broken fittings.
— Any liquid cooling systems are not leaking.
— All interlocks are operational.
— All warning indicators and lights are functioning properly.
— Fasteners are tight, and threaded connections are secure.

Maintenance

9.50. The operating organization should institute a programme of maintenance of X ray equipment. The programme should indicate that only the supplier or specially trained operators should perform this maintenance. The maintenance should be performed at least annually, and more frequently if the equipment is used in severe environments such as in excessively dirty or humid conditions, or if the equipment is frequently moved. The maintenance consists of a complete inspection and testing of the equipment, and a detailed inspection of all the components. Where required, non-functioning or damaged parts should be replaced and tested as necessary. Records should be kept of all maintenance, including replacement of parts.

10. RADIOGRAPHY IN SHIELDED ENCLOSURES

GENERAL

10.1. A shielded enclosure is an enclosed space designed and engineered to provide adequate shielding from ionizing radiation to persons in the vicinity. It incorporates engineering controls to prevent or to minimize the potential exposure of persons who might enter the enclosure when the sources are exposed or energized.

10.2. Industrial radiography should be carried out inside shielded enclosures whenever this is reasonably practicable. The use of a shielded enclosure provides the benefit of allowing other work in the vicinity (but outside the enclosure) to continue without interruption and allowing radiography work to be carried out as required. A correctly designed and constructed enclosure should be used for radiography work, with appropriate safety systems and warning systems, which are regularly tested and maintained. Such an enclosure can be very effective in

preventing accidents and keeping radiation doses as low as reasonably achievable.

10.3. Prior to the use of an enclosure, commissioning tests should be performed by the operating organization, if necessary with the support of the manufacturer, to confirm that the enclosure as built meets its design criteria.

DESIGN AND SHIELDING

10.4. A shielded enclosure should be designed to take account of the radiation sources that are to be used and the specific work that is to be carried out. The enclosure should be designed so that the exposure controls for the gamma source or radiation generator are located outside the shielded enclosure. The design should be planned for immediate and foreseeable future needs before the commencement of construction.

10.5. The design of the shielded enclosure should include a drawing of the installation and its surroundings, including any adjacent offices or buildings. The drawing should include dimensions, as well as the thicknesses, densities and types of shielding materials on all sides of, above and below the exposure area. Entrances should be marked and distances to potentially occupied areas adjacent to, above and below the exposure area should be indicated, including information on the occupancy factor (i.e. the frequency of occupation and the average duration that a person stays in an area). The facility should be properly planned to minimize the cost of the installation and to avoid costly remedial work, which may be required if the necessary degree of protection is not achieved.

10.6. Direct radiation exposure and radiation scattering arising from the operation of shielded enclosures should be limited by means of appropriate shielding. A comprehensive calculation of the required thicknesses of shielding requires the use of detailed transmission data for the relevant shielding material. The assistance of a qualified expert will be necessary to carry out these calculations. Guidance on the use of radiation transmission data and the necessary calculations is beyond the scope of this publication.

10.7. Enclosures should preferably have a shielded roof. In designs with minimal or no roof, special attention should be given to air scattering of radiation (or ‘sky shine’) and to scattering from objects outside the enclosure, such as higher ceilings or walls in the vicinity of the enclosure if it is to be constructed inside another building.

10.8. The regulatory body may specify the criteria to apply in designing an enclosure, including reference levels of dose or dose rate.

10.9. There will be some openings or penetrations of the shielding for personnel entry and exit points; for cranes to emplace and remove the heavy objects to be radiographed; for pipework; for control cables; and for ventilation and other ducting. These penetration points should be designed with great care to avoid, or at least to minimize, the penetration or scattering of radiation.

10.10. Weaknesses in the shielding can occur after a period of wear, damage to the shielding, movement of the shielding or settlement of the building. Various design techniques, such as maze entrances, should be used to prevent or to minimize these weaknesses.

10.11. The outcomes of the safety assessment[6] should be taken into account in the design. When the design of the shielded enclosure has been established, no subsequent changes should be made unless they maintain or enhance the level of safety. Changes to the original design may also require commissioning tests, and they may require authorization or approval by the regulatory body or a qualified expert.

10.12. All documents relating to the design of the enclosure should be kept for future reference. The regulatory body may also require copies of the plans and documentation prior to authorizing use of the facility.

CONTROLLED AND SUPERVISED AREAS

10.13. Dose rates will be very high inside an enclosure during radiography work, and the enclosure should be designated as a controlled area. However, an enclosure may not need to be designated as a controlled area when it is not in use. The approach adopted will depend on national or local regulations and requirements.

10.14. The shielded enclosure should be designed in such a way that there is no need to designate a controlled area outside the enclosure. Depending on the

[6] In the case of facilities where high energy radiation generators such as accelerators and cyclotrons are to be used, possible non-radiation hazards from noxious gases such as ozone may also need to be considered.

situation, the area surrounding the shielded enclosure might be designated as a supervised area.

SAFETY SYSTEMS AND WARNING SYSTEMS FOR GAMMA RADIOGRAPHY

Door interlocks

10.15. Shielded enclosures should be fitted with suitable safety systems on the access doors to ensure that people cannot enter while a radiation source is exposed. A mechanical or electrical interlock system should be installed to ensure that the source cannot be exposed unless the door is closed.

10.16. Likewise, the system should either prevent the door from being opened when the source is in the exposed position, or should automatically retract or shield the source in the event of the door being opened. With some manually operated gamma exposure devices, it may not always be possible to install interlock systems of this nature. In this case, the door should be locked closed by the radiographer immediately prior to exposing the source.

10.17. A radiation monitoring system with built-in 'fail-to-safe' features should be installed. Ideally, the radiation monitor should be integrated with the door interlocks to prevent entry to the shielded enclosure when the radiation monitor detects radiation in excess of a preset level. This may not be possible, however, with some manually operated gamma exposure devices with wind-out equipment.

10.18. The same installed radiation monitor should trigger visible and audible signals when the source is exposed. Even when such automatic systems are used, persons entering the shielded enclosure should always use a correctly functioning portable radiation meter to confirm that the source is fully shielded.

Warning signals and notices

10.19. A pre-warning signal, which may be either visible or audible, should be given immediately prior to exposing a source. This signal should be clear to any person inside or at the entrance to the shielded enclosure. It should last sufficiently long to enable persons to vacate the inside of the enclosure.

10.20. A second visible or audible warning signal should be given while the source is in the exposed position. The pre-warning signal and the 'source

exposed' warning signal should be clearly distinguishable from one another, and both should be visible and/or audible from within the shielded enclosure.

10.21. Preferably, both signals should be installed so that they operate automatically when a source exposure is made. However, depending on regulatory requirements, it may be acceptable for the pre-warning signal to be manually generated by the radiographer immediately prior to making the exposure. In cases where there is more than one radiation source, the exposure controls and the warnings should be distinct and unambiguous.

10.22. Visible notices that clearly explain the significance of the pre-warning and 'source exposed' signals should be posted at appropriate locations in and around the facility. The notices should incorporate the radiation trefoil and other information as required by the regulatory body. The text of the notice should be written in a language known by persons likely to be in the areas around the shielded enclosure.

10.23. The notices should be made from materials that are durable under the prevailing environmental conditions. Damaged or unreadable notices should be replaced as necessary.

Emergency stop buttons or pull-cords

10.24. Emergency stop buttons or pull-cords with manual resets should be installed to enable any person within the shielded enclosure to trigger an alarm immediately and to terminate or prevent radiation exposure, either automatically or by attracting the attention of the radiographer. The buttons and pull-cords should be so located that they can be reached without passing through the primary radiation beam. They should be labelled with clear instructions on their use. Persons inside the enclosure should be able either to leave rapidly or to shelter behind suitable shielding. The radiographer should be able to terminate the exposure immediately in an emergency.

SAFETY SYSTEMS AND WARNING SYSTEMS FOR X RAY GENERATORS

10.25. X ray generators are used for carrying out radiography work in shielded enclosures. The radiation output of X ray generators is generally several orders of magnitude higher than that of gamma sources. The safety systems should be carefully and correctly installed to prevent inadvertent exposure of radiographers

and other workers. X ray generators should normally be integrated into the safety systems and warning systems of an enclosure, so that it is not possible to operate the X ray generator without the safety systems being in operation.

Door interlocks

10.26. Shielded enclosures should be fitted with suitable interlocks on the access doors, to ensure that no one can access an enclosure while an X ray generator is generating radiation. An interlock system should be installed to provide a mechanical or electrical link between the exposure control system and the door or other points of entry to the shielded enclosure. The interlock should prevent the generation of X rays until the door is closed, and it should immediately terminate the production of X rays if the door is opened. Subsequent closing of the door should not automatically re-energize the X ray generator.

10.27. Door interlocks should not hinder people who may be in the enclosure from leaving in an emergency. Common interlock systems incorporate electrical switches or captive key systems. Interlock systems should be fail-to-safe, so that X rays cannot be generated if any component of the interlock system has failed or is broken. Redundancy, diversity and independence of interlock systems should be used as necessary to provide additional levels of safety.

Warning signals and notices

10.28. A pre-warning signal, which may be either visible or audible, should be given immediately prior to the generation of X rays. This signal should be clear to any person inside or at the entrance to the shielded enclosure. It should last sufficiently long to enable persons to vacate the inside of the enclosure[7].

10.29. A second visible or audible warning signal should be given while X rays are being generated. The pre-warning signal and the 'X rays on' warning signal should be clearly distinguishable from one another, and both should be visible and/or audible from within the shielded enclosure. They should also be selected so as not to be confused with any other warning signals in use in the area.

[7] In facilities with high energy radiation generators such as linear accelerators, additional safety measures such as 'search and lock up' systems can be installed to 'force' the operator to check physically that the room is empty before initiating the exposure.

10.30. The signals should be installed so that they operate automatically when an X ray exposure is initiated. The warning signal system should be designed and/or installed so that X rays cannot be generated in the event of the failure of any component of the system (e.g. failure of a light bulb). In cases where there is more than one radiation source, the exposure controls and the warnings should be distinct and unambiguous.

10.31. Visible notices that clearly explain the significance of the pre-warning and 'source exposed' signals should be posted at appropriate locations in and around the facility. The notices should incorporate the radiation trefoil and other information as required by the regulatory body. The text of the notice should be written in a language known by the persons likely to be in the areas around the shielded enclosure.

10.32. The notices should be made from materials that are durable under the prevailing environmental conditions. Damaged or unreadable notices should be replaced as necessary.

Emergency stop buttons or pull-cords

10.33. Emergency stop buttons or pull-cords with manual resets should be incorporated into the interlock system, to enable any person within the shielded enclosure to trigger an alarm immediately and to automatically prevent or terminate radiation exposure. The buttons and pull-cords should be so located that they can be reached without passing through the primary radiation beam. They should be labelled with clear instructions on their use. Persons inside the enclosure should be able either to leave rapidly or to shelter behind suitable shielding. The radiographer should be able to terminate the exposure immediately in an emergency.

PROCEDURES FOR RADIOGRAPHY

10.34. Radiography work in a shielded enclosure should be performed only by competent radiographers who have received appropriate training. Training should include instruction to ensure that the shielded enclosure is used within its design constraints and that all systems and components of the facility are maintained to the original specifications. The radiographers should also have an understanding of the installed safety systems and warning systems and of the ways in which they should be operated.

10.35. Operating organizations should ensure that written operating procedures and emergency procedures for radiography work performed in the shielded enclosure are readily available in a language known to the radiographers.

10.36. No radiography work should be performed in a shielded enclosure other than that for which it was designed and for which a safety assessment has been carried out. Radiography work that was not considered in the original design and safety assessment should be performed only after a new safety assessment has been performed and any necessary modifications have been approved and made.

10.37. Radiographers should always wear personal dosimeters as required by the regulatory body. Personal dosimeters include thermoluminescent dosimeters, personal direct reading dosimeters and personal alarm dosimeters.

10.38. Radiographers should not rely on the installed safety systems to restrict their radiation exposures. They should carry a suitable radiation survey meter whenever they enter the shielded enclosure. In the event of dose rates above a preset level being measured, the radiographer should immediately vacate the enclosure, prevent access by others and seek advice from the radiation protection officer.

10.39. A suitable portable survey meter should be available for measuring dose rates outside the shielded enclosure (see also Section 7). The measurements should be made at a range of positions around the enclosure, including the operator's position and adjacent occupied areas. The measured dose rates should be compared with reference levels. In the event of dose rates being higher than the reference levels, the work should be terminated and advice should be sought from the radiation protection officer.

10.40. The functionality of the survey meter should be checked at the beginning of each shift, and should preferably be checked during each shift. A check should be performed in accordance with the operating manual of the meter. The check should include a test of the battery voltage and of the response of the meter to a test source. If a check fails, radiography work should not commence or proceed until a good working survey meter is available.

10.41. Collimators and additional shielding should be used as appropriate to minimize potential exposure.

10.42. Before every exposure the radiographer should verify that no one is inside the shielded enclosure and should close the door. Exposures should be initiated

by the radiographer only when the door is closed, all shielding is in place, and the safety systems and warning features are operational.

10.43. If it is necessary to use the shielded enclosure for purposes not originally considered in the design specification, such as radiographing unusually long vessels by keeping the door open, or using a gamma exposure device in an X ray radiography shielded enclosure, then site radiography work procedures should be followed. This may require authorization by the regulatory body.

10.44. Barriers and notices should be used to define the controlled area, dose rates should be monitored around the barriers, and continuous supervision should be provided to ensure that no one enters the controlled area. If interlocks have to be temporarily disabled, this should be clearly specified and considered in a specific safety assessment. The return to normal use should be checked before the next use of the enclosure.

DECOMMISSIONING

10.45.When an industrial radiography facility is no longer used, and there are no plans to use it again in the foreseeable future, the facility should be formally decommissioned [29, 30]. All sources of radiation should be dealt with in a manner that is consistent with the national regulatory framework and, if required, is subject to approval by the regulatory body. This should include the following:

(a) Gamma sources should, subject to approval by the regulatory body, be transferred to another authorized organization. Alternatively, the operating organization should return the source to the original supplier or should take other 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).
(b) Exposure devices incorporating depleted uranium should be treated in the same manner as gamma sources.
(c) X ray generators should be made inoperable or, subject to approval by the regulatory body, should be transferred to another authorized organization.
(d) X ray pipeline crawlers may incorporate low activity gamma sources, which should also be considered.
(e) Operating organizations should inform the relevant authorities when all sources of radiation have been removed from the site.

(f) All radiation trefoils and notices should be removed.
(g) A comprehensive radiation survey should be made, to confirm that no radioactive sources have been left on the site and that there is no contamination.
(h) A final decommissioning report should be prepared that includes the final radiation survey and details of the storage, transfer or disposal of sources of radiation. The final decommissioning report should be submitted to the regulatory body [29, 30].

11. SITE RADIOGRAPHY

GENERAL

11.1. When objects to be radiographed cannot be physically moved into a shielded enclosure, the work should be carried out under 'site radiography' conditions. This method of radiography is very common, but it is potentially hazardous because of the absence of engineered safety measures.

11.2. The location for site radiography work may be, for example, at the premises of the client (e.g. in a refinery, an offshore location or a construction workshop), in an urban area (e.g. at a gas pipeline or a building construction site) or in an open field (e.g. a pipeline through a rural or an uninhabited area).

11.3. Site radiography work should be carried out only when it is not practicable to perform radiography in a shielded enclosure. This might be the case because the objects to be radiographed are permanently fixed in location or are too large or heavy to be moved. Where it is practicable to move workpieces, they should be radiographed in a shielded enclosure with all safety provisions as described in Section 10.

11.4. Site radiography work can be performed with gamma radiography devices, X ray equipment or mobile accelerators.

PREPARATION FOR SITE RADIOGRAPHY

11.5. Site radiography work is influenced by a number of site specific conditions. Planning for safe operation includes consideration of the location, the proximity of workers and members of the public, weather conditions, the time of day, and whether work is necessary at a height, in confined spaces or under other difficult conditions. Prior to radiography work, a thorough assessment of the working environment should be made by the operating organization to identify any site specific issues that should be addressed.

11.6. Operating organizations carrying out site radiography work should ensure that at least two radiographers, one of whom should be a radiation protection officer (unless otherwise stated in the regulatory requirements), are available for each source of radiation.

COOPERATION WITH THE CLIENT

11.7. Where radiography work is to be carried out 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. This should include the selection of a suitable location and time for the radiography work to be carried out. The notices, warning signals and alarms to be used in the radiography work should be discussed between the parties, to avoid possible confusion on the site, while remaining consistent with regulatory requirements.

11.8. The client should provide information on any radiation detection systems (such as some types of smoke detector) on the premises, as these may be affected by the radiography work. The radiographers should be aware of any site specific hazards. Any work permit system of the client should be followed. The client should be provided with a copy of the operating organization's local rules and emergency plans.

11.9. The operating organization and the client should agree on the planned timescale of the work and the duration of the period over which radiography work will be performed. The client should allow the radiographers sufficient time for the radiography work to be performed safely and for all the required safety measures to be taken.

11.10. The operating organization should inform the client about the type of radiation source that it is planning to use on the site. It should ensure that proper

storage is available for any radioactive sources that are intended to be stored on the site overnight (this may require separate authorization by the regulatory body).

DEMARCATING THE BOUNDARY OF THE CONTROLLED AREA

11.11. Site radiography work should be carried out in an area designated as a controlled area. No other work should be permitted in this area until the radiography work has been finished and the controlled area is no longer so designated. The boundary of the controlled area should be set to ensure that possible doses to people outside the controlled area are below the relevant reference dose levels.

11.12. The regulatory body may specify maximum permitted dose rates at the barriers during site radiography work, typical values being 2.5–20 $\mu Sv \cdot h^{-1}$. To limit the extent of the controlled area, collimators should be used where practicable on both X ray generators and gamma radiography sources. Additional local shielding should also be used as appropriate (e.g. lead sheets).

11.13. The boundary of the controlled area should be demarcated. When reasonably practicable, this should be done by physical means. This should include using existing structures such as walls, using temporary barriers or cordoning off the area with tape. Care should be taken to ensure that unauthorized access to the controlled area is prevented.

11.14. Particular care should be taken where radiography work is being performed in an industrial plant or on a construction site with several floors that can be occupied by people and where there are ladders, stairways, etc. Radiographers should ensure that access is prevented to any controlled areas on floors above and below the work area.

11.15. Radiographers should place the radiation generator control panel or the gamma wind-out in such a position as to minimize doses to themselves when initiating and ending an exposure.

WARNING SIGNALS

11.16. Adequate warning signals should be given that a radiation exposure is about to be made, and that radiation is being generated or a gamma source is exposed. These signals should be distinguishable from each other. They should be

either audible or visible. In general, pre-warning signals are audible (a siren, whistle or bell) while 'exposure in progress' signals are visible lights (e.g. flashing beacons). These signals can be operated manually when radioactive sources are being used. They should operate automatically with X ray equipment.

11.17. The signals should be clearly audible and/or visible from all points around the barrier of the controlled area. Supplementary slave signals may need to be incorporated into the warning system.

NOTICES

11.18. Notices should be displayed at suitable positions on the boundary of the controlled area. The notices should bear the radiation symbol (trefoil), warnings and appropriate instructions in a language known locally. They should also explain the meaning of the 'exposure pre-warning' and 'exposure warning' signals. In some cases, it may be appropriate to post additional notices at the entrance to the premises, to inform persons entering the site that radiography work is due to take place.

PATROLLING AND MONITORING THE BOUNDARY

11.19. Before the start of radiography work, the area should be cleared of all persons except for the radiographers who will be performing the radiography work. Prior to initiating an exposure, the radiographers should confirm that there are no persons within the controlled area and that access to the area is prevented.

11.20. The boundary of the controlled area should be clearly visible, well lit and constantly patrolled during radiography work, to ensure that no unauthorized persons enter the area. More than one person should patrol the boundary if the area is large or if from certain positions it cannot all be seen.

11.21. Dose rates should be measured around the barriers during a test exposure (or during the first exposure, depending on the circumstances) to confirm that the barriers are correctly positioned. The boundary and the demarcation of the controlled area should be adjusted if necessary.

MONITORING

Portable survey meters

11.22. For site radiography operations, there should be at least one portable survey meter available for each radiography source. Prior to the commencement of radiography work, the meter should be tested, either against a test source or against an exposure device, to obtain a reference reading. The test against an exposure device containing a radioactive source should show that the meter is working correctly and should also confirm that the gamma source is in the shielded position.

11.23. During radiography work, the primary objective of monitoring is to determine that a gamma source is in its shielded position or that X ray emission has ceased after each exposure. Radiography devices should always be approached with the portable survey meter switched on, since there is a possibility that the gamma source has become stuck in the exposed position or that the termination of the X ray exposure has failed.

Personal dosimeters and alarm monitors

11.24. Personal dosimeters such as thermoluminescent dosimeters and direct reading dosimeters should be worn by radiographers at all times when they are performing site radiography work. Direct reading dosimeters (see Section 6) should be periodically assessed by the radiographers to monitor the doses received during the work.

11.25. Personal alarm monitors (see Section 6) are particularly useful in site radiography work. They should be recognized as a major aid in identifying possible incidents. These alarms can be preset to trigger above a specified dose rate. They can provide an audible, visible or vibrating signal when a radiographer enters an area of high dose rate.

11.26. Radiographers should wear a personal alarm monitor during the entire period for which they may be exposed to ionizing radiation. Personal alarm monitors should not, however, be considered alternatives to portable survey meters, which should also be used.

ADDITIONAL PRECAUTIONS FOR SITE GAMMA RADIOGRAPHY

Equipment

11.27. Only equipment that is specifically manufactured for gamma radiography should be used for site gamma radiography. The radiographer should be familiar with all the equipment, its mode of operation and its potential problems. The radiographer should also have an understanding of the source, its appearance and the manner in which it is exposed, which is particularly important.

11.28. The selection of which radionuclide to use for gamma radiography should normally be determined in accordance with the type and physical size of the object to be radiographed. For operating organizations that have several gamma sources, the lowest activity source consistent with obtaining the desired radiograph should be used. If there is a choice between using, for example, a 370 GBq or a 3700 GBq ^{192}Ir source, and if either would produce the desired radiograph, then the 370 GBq source should be used.

11.29. Using lower activity sources can have several benefits, such as:

— Smaller controlled areas which are easier to manage;
— Lower dose rates at the barriers and at the operator's position;
— Less difficulty if the source becomes jammed.

The use of advanced techniques should be considered, such as image intensification or fast film and screen combinations. Such techniques should be used, where possible, to help reduce doses to the operators.

11.30. Radiography work should only be performed when the exposure device and all the necessary items of equipment are available and in good working order. These items should include:

(a) Portable survey meters (including spare batteries) and personal dosimeters;
(b) Guide tubes, control cables and remote controls;
(c) Collimators and local shielding;
(d) Temporary barriers or tapes;
(e) Notices and warning signals;
(f) Emergency kits, including remote source handling tools and a spare shielded container for emergency use;
(g) Other ancillary equipment, such as clamps to ensure that the exposure device or guide tube is securely positioned, and positioning aids.

11.31. The following checks should be made before use of gamma radiography equipment, and should be described in the operating procedures:

(a) Check the exposure device and ends of cables for damage, wear or dirt. A wear gauge such as a 'go/no-go' type check gauge supplied by the manufacturer should be used for this purpose.
(b) Check screws and nuts for tightness and screw threads and springs for damage.
(c) Confirm that the source locking mechanism is working properly.
(d) Examine the end of the source pigtail for wear, damage and proper connection to the control cable. A wear gauge provided by the manufacturer should be used for this purpose.
(e) Check connections between the exposure device and cables for secure connection.
(f) Inspect all cables and guide tubes for cuts, breaks, kinks and broken fittings.
(g) Check the warning label and source tag details for legibility.
(h) Measure radiation levels close to the surface of the exposure device and confirm that the source is shielded.
(i) Check the functionality of the survey meter in accordance with the operating manual.

11.32. If any faults are found, the equipment should not be used until a replacement is provided or a repair is made.

Transient dose rates

11.33. Transient dose rates outside the boundary during wind-out and wind-in operations for the radiography source will be much higher than the dose rates during actual exposure when the source is in its collimator. Additional care should be taken during these operations, especially to confirm that there are no persons standing at the boundary of the controlled area, and wind-out and wind-in operations should be conducted quickly.

Storage of radioactive sources at remote locations

11.34. Exposure devices containing radioactive sources should if necessary be stored on-site overnight or between radiography sessions. The need for such storage should be identified in the planning phase, and arrangements should be made with the site operator for the provision of suitable storage facilities that comply with the regulatory requirements.

11.35. On-site storage facilities should consist of a lockable room, purpose-built store or storage pit. They should provide the same level of protection as storage facilities at the operating organization's main base. A suitable storage facility should provide protection of exposure devices from the prevailing environmental conditions and should also provide an adequate level of safety. The store should be resistant to fire, to minimize the potential for loss of shielding and loss of containment in the event of a fire in the vicinity. The store should be located at a remote distance from any corrosion and explosion hazards.

11.36. The store should be built of materials that provide sufficient shielding to reduce dose rates outside the store to below the relevant levels specified by the regulatory body. The store should be designated as a controlled area or supervised area as necessary.

11.37. The door to the storage facility should be kept locked and the keys should be held only by authorized personnel. A warning notice incorporating the radiation symbol (trefoil) should be displayed on the door.

Completion of work and removal of sources from site

11.38. On completion of the radiography work, radiographers should use a radiation monitor to ensure that all gamma sources have been fully retracted into the exposure device and that no sources have been left in the exposed position or have become detached.

11.39. Before leaving the site, the radiographer should carry out a visual examination to ensure that equipment has not been damaged. Exposure devices should be made ready for transport by locking the devices and putting the protective covers in place. The exposure device and the ancillary equipment should be physically secured in the vehicle to avoid damage during transport.

ADDITIONAL PRECAUTIONS FOR SITE X RAY RADIOGRAPHY, INCLUDING THE USE OF ACCELERATORS

11.40. The procedures discussed in this section are applicable to the use of X ray equipment and techniques, including the use of accelerators and real time radiography. Selection of the voltage of the X ray tube is normally closely linked to the requirements for the quality of the radiograph. The exposure technique (e.g. with the source internal or external to the workpiece, with single wall or

double wall radiographs) should be selected with regard to both good image quality and minimization of doses to persons in the vicinity.

11.41. The following checks should be made before use and should be described in the operating procedures:

(a) Check all parts of the equipment for visible damage.
(b) Check the X ray tube and all bare ends of the cable for damage, wear, dirt and moisture.
(c) Check screws and nuts for tightness and screw threads for damage.
(d) Inspect all cables for cuts, breaks, kinks and broken fittings.
(e) Check exposure factor settings for legibility.

11.42. If any faults are found, the equipment should not be used until a replacement has been provided or a repair has been made.

11.43. Accelerators generate very high energy X rays. The dose rate in the main beam of an accelerator can range from 50 mGy/min (3 Gy/h) from a portable accelerator to 4 Gy/min (240 Gy/h) from a mobile accelerator. The dose rate around the apparatus is much higher than for conventional X ray radiography. More comprehensive control measures should be taken to restrict the exposure to radiation of radiographers and others in the vicinity.

11.44. In addition, appropriate portable survey meters should be used that respond accurately to the pulsed nature of the radiation field. Portable survey meters used for conventional gamma and X ray radiography should be confirmed to be suitable prior to use with accelerators.

12. TRANSPORT OF RADIOACTIVE SOURCES

MOVEMENT WITHIN THE WORKSITE

12.1. When gamma exposure devices and sources are to be moved within a site for radiography work, they should be kept in the storage facility until they are to be moved to the new location. Ancillary equipment should be disconnected from the devices, and all required plugs and caps should be installed prior to movement.

12.2. The sources should be moved only in exposure devices, and these should be locked and the keys should be removed. If a vehicle or trolley is used to move the exposure device, the device should be securely fastened to the vehicle or trolley. The exposure devices should be kept under surveillance for the duration of the movement on the worksite.

TRANSPORT TO ANOTHER SITE

12.3. When gamma radiography sources are to be transported to another worksite for site radiography purposes, they should be kept in the storage facility until they are to be moved to the new site. As described above, ancillary equipment should be disconnected from the devices, and all required plugs and caps should be installed prior to transport.

12.4. The sources should be moved only in packages, and these should be locked and the keys should be removed. The operating organizations should ensure that the transport and the transport packages comply with the IAEA Regulations for the Safe Transport of Radioactive Material [23] or equivalent national regulations.

12.5. 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 [31] of the International Civil Aviation Organization (ICAO), and the International Maritime Dangerous Goods (IMDG) Code [32] of the International Maritime Organization (IMO).

12.6. Regional agreements such as the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) [33], the Agreement of Partial Reach to Facilitate the Transport of Dangerous Goods, Signed by the Governments of Argentina, Brazil, Paraguay and Uruguay (MERCOSUR/MERCOSUL) [34], and the European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) [35] may also apply.

12.7. The IAEA Transport Regulations [23] assign responsibilities for individuals involved in the transport of radioactive material: the consignor (a person, organization or government that prepares a consignment for transport), the carrier (the person, organization or government that undertakes transport of radioactive material) and the consignee (the person, organization or government

that receives a consignment). In many cases, for site radiography work, the operating organization will perform all three functions and is required to discharge the responsibilities associated with each function.

12.8. Transport of radioactive material is a complex activity, and a comprehensive overview of the relevant requirements is outside the scope of this Safety Guide. Guidance on how to meet transport related requirements is provided in Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material [36].

12.9. Guidance on security in the transport of radioactive material has been issued by the IAEA [37].

13. EMERGENCY PREPAREDNESS AND RESPONSE

GENERAL

13.1. Radiation sources used for industrial radiography purposes have high radiation outputs and are potentially very hazardous. Incidents have occurred mainly as a result of operator error or equipment failure, and have resulted in workers and members of the public receiving high radiation doses [14–18].

13.2. Typical situations that have led to incidents include damage being caused to the radioactive source or the exposure device, leading to a source becoming jammed in the exposed position, and separation of the source pigtail from the wind-out cable, leading to the source being inadvertently left on-site.

13.3. Serious radiation overexposures have occurred when workers have physically handled an unshielded source, or when a lost radioactive source has been found and taken by a member of the public. The dose rates in these situations are high enough to injure people in a matter of seconds or minutes. In some cases, severe radiation burns have resulted, necessitating amputation or leading to other serious health consequences.

13.4. In many cases, incidents involving industrial radiography sources could have been prevented or their consequences could have been mitigated if the following precautions had been taken:

(a) Radiographers:
- Should be properly trained and qualified, and they should be competent;
- Should follow the local rules and other relevant procedures;
- Should use survey meters before, after and during every exposure;
- Should make regular and appropriate inspections of equipment and survey meters prior to use;
- Should make proper use of emergency equipment;
- Should make a final survey of the work area before leaving the site.

(b) Radiography equipment (including ancillary equipment) should meet current standards.

13.5. Although prevention of incidents is the first defence, emergencies still occur. Operating organizations should have emergency plans prepared in advance, so as to be able to respond quickly and safely to mitigate an incident. Once an emergency is over, a report should be prepared. The report should include a critical review of how the procedures were implemented, what lessons can be learned to prevent similar incidents in the future, and how the response plans could be improved.

13.6. This section describes potential incidents and emergencies in industrial radiography and provides recommendations for the development of emergency plans to mitigate the consequences of incidents and emergencies.

DEVELOPMENT OF EMERGENCY PLANS

13.7. Requirements on obligations and responsibilities for emergency preparedness and response are given in the BSS [2] and in two IAEA safety standards [38, 39]. Guidance on developing and implementing emergency plans and on a step by step method for developing an integrated capability for emergency response at the organizational, local and national levels is also available from the IAEA [40]. When site radiography work is carried out on a client's premises, the emergency plans should be discussed with the client.

13.8. Potential incidents that could affect workers, members of the public or the environment should be identified in the operating organization's safety assessment. This should be used as a basis for preparing emergency plans and procedures for responding to such events. A qualified expert should be consulted, where possible, when drawing up emergency plans and procedures.

13.9. Emergency preparedness arrangements can be regarded as comprising several stages, each of which should be addressed by the operator:

(a) Identification of potential incidents during industrial radiography work, followed by an evaluation of the associated risks;
(b) Development of emergency plans and procedures for dealing with the risks identified;
(c) Specification and acquisition of emergency equipment;
(d) Training in implementing the emergency plan and procedures, including training as necessary in the use of emergency equipment;
(e) Exercises at appropriate intervals to test and evaluate the implementation of the emergency plan;
(f) Periodic reviews and updates of emergency plans;
(g) Reports and notifications of incidents and emergencies.

13.10. Implementation of the emergency plan may involve response by external organizations and specialist consultants. The plan should clearly give details of any external response, and it should be ensured that the responders are fully aware of and accept their responsibilities. In particular, arrangements should be made for a system for immediate and efficient communication between all the parties involved. Operating organizations should submit their emergency plans and associated arrangements to the regulatory body, as required, when applying for an authorization.

TYPES OF EMERGENCY

13.11. A review of emergencies in radiography shows that there are several types of incident that have historically occurred commonly with industrial radiography sources. Operating organizations should consider the types of incident listed in paras 13.12 and 13.13 below in their emergency plans, as appropriate.

13.12. For gamma radiography equipment, the operating organization should consider incidents in which:

(a) A source becomes stuck in the guide tube or the collimator, or near the entrance to the exposure device.
(b) Physical damage is caused that affects the shielding.
(c) A source becomes disconnected from its drive cable and remains in the guide tube.
(d) A source is projected out of the end of the guide tube.

(e) A pipeline crawler becomes stuck in a pipe with the source exposed.
(f) A source is lost.
(g) There is a fire.
(h) Unauthorized persons are present in the controlled area during an exposure.

13.13. For X ray generators, the operating organization should consider incidents in which:

(a) Generation of radiation fails to terminate after the intended time period.
(b) An X ray generator is unintentionally energized.
(c) A radiographer fails to terminate a manually controlled generation of radiation.
(d) A safety system or warning system malfunctions, including deliberate action to override a system.
(e) Another malfunction causes X rays to be generated other than in a controlled manner.
(f) Physical damage is caused that affects the shielding or filtration.
(g) Unauthorized persons are present in the controlled area during an exposure.

CONTENT OF A BASIC EMERGENCY PLAN

13.14. Operators should ensure that emergency plans address reasonably foreseeable emergencies as identified in the safety assessment. For emergencies in industrial radiography, the specific response will be dependent on the type of event and may vary depending on the local conditions, such as when radiography is carried out from scaffolding or on a pipeline in a ditch.

13.15. The emergency plan should allow for flexibility in the response, with rehearsal of the specific elements of the response prior to implementation of the plan. The plans should aim to restrict, as far as is reasonably achievable, any exposures that could result from the incident. The emergency plan should include the following:

(a) Advice on when to implement the emergency plan.
(b) Prior training as necessary for workers who will be implementing the procedures.
(c) Description of, and information on, the availability of emergency response equipment.
(d) Technical data and data relevant to radiological protection for each situation.

(e) Procedures to be followed at various stages, specific to each type of emergency identified:
  (i) Initial stage, to contain the situation;
  (ii) Planning stage, to plan and rehearse the recovery stage;
  (iii) Recovery stage, to regain control of the situation;
  (iv) Post-emergency stage, to return the situation to normal;
  (v) Reporting stage: preparation of a report, including an assessment of doses;
  (vi) Referral to medical experts following overexposure, if indicated.
(f) Identification of persons authorized to implement the various stages of the plan.
(g) Identification of all persons and organizations who should be contacted as necessary at the various stages of the plan, as well as the relevant telephone numbers, fax numbers and email addresses.

13.16. To minimize exposures and to allow for a proper response, the operating organization should as a minimum do the following:

(a) Restrict access to the vicinity of the source — ensure that controlled area barriers are in the correct place for a given situation;
(b) Ensure that the radiation protection officer is notified (and a qualified expert as necessary);
(c) Remain calm, move to a safe distance, plan subsequent actions, rehearse the actions without the source and then implement the plan;
(d) Never enter areas of potentially high, but unknown, dose rates unless carrying a functional survey meter and, preferably, wearing a personal alarm monitor and/or direct reading dosimeter;
(e) Never touch a radioactive source or allow the hands to come close to it;
(f) Do not exceed authority or personal expertise;
(g) Seek assistance from a qualified expert or from the source supplier if necessary.

EMERGENCY EQUIPMENT

13.17. Operators should ensure that all necessary emergency equipment for dealing with all reasonably foreseeable emergencies is readily available. Regular audits should be made to ensure that all necessary emergency equipment is available and that it all functions correctly.

13.18. For emergencies involving gamma radiography sources, the following equipment should be available:

— Appropriate and functional survey meters to measure both high and low dose rates;
— Personal alarm dosimeters and direct reading dosimeters (preferably electronic personal dosimeters rather than quartz fibre electroscopes);
— Additional personal dosimeters (thermoluminescent dosimeters and/or film badges);
— Barrier materials and notices;
— Bags of lead shot, and extra lead sheet;
— Suitable tool kit and source recovery equipment (long handling tongs, pliers, screwdrivers, bolt cutters, adjustable spanner, hacksaw and torch);
— Spare shielded container for emergency use;
— Communication equipment (e.g. mobile phones, radio transmitters and receivers);
— Spare batteries for survey meters, electronic personal dosimeters, mobile phones and torches;
— Pens, paper, calculator and an incident log book;
— Equipment manuals.

13.19. If it is suspected that the 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 needs specialized monitoring equipment and expertise, to which most companies performing radiography work are unlikely to have ready access. If it is known or suspected that a source capsule has been ruptured, the operating organization should promptly seek advice from a qualified expert.

SPECIFIC EMERGENCY PROCEDURES

Gamma sources

13.20. This section provides practical guidance for emergencies involving gamma sources used for industrial radiography purposes. Although the steps are listed in the sequence in which they should generally be performed, the sequence should if necessary be adapted at the time of the response. As with any radiological emergency, the first priority should be the protection of persons.

The *radiographer (response initiator)* should:

(a) Recognize that an abnormal situation has arisen that might constitute an emergency.
(b) Remain calm and move away from the exposed source. Ensure that any other radiographers in the vicinity are aware that there may be a problem.
(c) Measure the radiation dose rates and record any doses measured by direct reading dosimeters.
(d) Establish or re-establish controlled area barriers on the basis of dose rate reference levels consistent with regulatory requirements and guidance.
(e) Prevent access to the new controlled area.
(f) Do not leave the controlled area unattended.
(g) Inform the radiation protection officer of the operating organization and the radiography client, and seek assistance.

The *radiation protection officer* should:

(a) Plan a specific course of action on the basis of previously established emergency procedures, taking care to minimize doses that may be received as a result of this course of action.
(b) Move to an area 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 and authorizations allow; under no circumstances allow the source to 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.
(f) When the emergency is over and the source has been made safe, assess the doses received and prepare a report.
(g) Return personal dosimeters to the dosimetry service for the purpose of accurate assessment of exposures.
(h) Send damaged or malfunctioning equipment to the manufacturer or to a qualified expert for detailed examination and repair prior to any reuse.
(i) Prepare an accident report and notify the regulatory body as required.

X ray generators

13.21. The following steps should be taken in an abnormal situation involving an X ray generator.

The *radiographer (response initiator)* should:

(a) Recognize that an abnormal situation has arisen that might constitute an emergency.
(b) Turn off the electrical power to the radiography equipment.
(c) Perform a radiation survey to confirm that the tube is de-energized.
(d) Do not move the radiography equipment until details such as position, beam direction and exposure settings (tube voltage, current and time) have been recorded.
(e) Inform the radiation protection officer of what has happened.
(f) Do not use the X ray generator until it has been examined and repaired by the manufacturer or by a qualified expert.

The *radiation protection officer* should:

(a) Assess the possible doses that could have been received and prepare a report.
(b) Return personal dosimeters to the dosimetry service for the purpose of accurate assessment of exposures.
(c) Prepare an accident report and notify the regulatory body as required.

TRAINING AND EXERCISES

13.22. All persons who will participate in implementing the emergency plans should be adequately trained for the effective fulfilment of their roles. This should include both familiarization with and understanding of the plans, together with specific training on source recovery procedures and on the use of the emergency equipment.

13.23. Individual workers should implement only those parts of the emergency plans 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.

13.24. Emergency exercises should be held to test critical components of the emergency plans, at intervals that are commensurate with the potential hazard. Any lessons learned should be fed back into reviews of the emergency plans.

PERIODIC REVIEWS OF PLANS AND EQUIPMENT

13.25. Formal reviews of emergency plans should be undertaken every year to ensure that:

(a) All persons and organizations have been identified that should be contacted as necessary at the various stages of the plans, and the relevant telephone numbers, fax numbers and email addresses are up to date.
(b) Emergency equipment is readily available and is maintained.

13.26. The periodic reviews should include provision to update any relevant aspects of the emergency plans in response to lessons learned from exercises or from incidents and emergencies.

REPORTING

13.27. The primary objective of emergency preparedness and response should be to mitigate the consequences of emergencies. However, it should be of similar importance to critically review situations that have occurred so that the lessons learned can provide feedback for improving equipment, maintenance procedures, operating procedures and emergency plans. To this end, a comprehensive report should be made of any emergency or incident.

13.28. Reports of any emergencies or incidents should be prepared by the radiation protection officer with the assistance of qualified experts if necessary. The reports should be submitted to senior management and to the regulatory body as required. If the emergency could have been caused by an equipment malfunction, the supplier should be notified so that the equipment can be evaluated and appropriate action taken.

13.29. A report of an incident or an emergency should include the following:

(a) A description of the incident or emergency, with as much detail as possible of the specific equipment involved. The details should include model numbers and serial numbers wherever possible.

(b) Environmental conditions at the time of the incident or emergency, with particular reference to whether or not these conditions played any significant part in causing the emergency or incident or affecting the outcome.
(c) The specific cause of the incident or 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 training and experience of the personnel involved.
(f) An assessment and summary of the doses received by all affected persons.
(g) Recommendations made with the aim of preventing similar incidents and emergencies in the future, and mitigating the consequences if a similar or related incident or emergency were to occur.

13.30. A copy of the report should be sent to the regulatory body, especially where this is required by the conditions of the authorization or by national regulations. The lessons learned should be communicated to all involved, including the manufacturer if relevant, and any necessary improvements to enhance safety should be carried out.

Appendix

IAEA CATEGORIZATION OF RADIOACTIVE SOURCES

A.1. The IAEA Safety Guide on Categorization of Radioactive Sources [19] provides a system of categorization, in particular for radioactive sources used in industry, medicine, agriculture, research and education. Its system can also be applied, where appropriate in the national context, to radioactive sources within military programmes.

A.2. The Safety Guide [19] provides an internationally harmonized basis for risk informed decision making. It is based on a logical and transparent method that provides the flexibility for it to be applied in a wide range of circumstances. Risk informed decisions can be made in a graded approach to the regulatory control of radioactive sources for the purposes of safety and security.

A.3. The categorization system is based on the concept of 'dangerous sources' — which are quantified in terms of '*D* values' [41]. The *D* value is the radionuclide specific activity of a source which, if not under control, could cause severe deterministic effects for a range of scenarios that include both external exposure from an unshielded source and internal exposure following dispersal of the source material.

TABLE A.1. ACTIVITY OF RADIONUCLIDES USED IN INDUSTRIAL RADIOGRAPHY, CORRESPONDING TO THRESHOLDS OF CATEGORIES

Radionuclide	Category 1		Category 2		Category 3	
	1000 × *D*		10 × *D*		*D*	
	(TBq)	(Ci)[a]	(TBq)	(Ci)[a]	(TBq)	(Ci)[a]
Cobalt-60	3.0×10^{1}	8.0×10^{2}	3.0×10^{-1}	8.0	3.0×10^{-2}	8.0×10^{-1}
Caesium-137	1.0×10^{2}	3.0×10^{3}	1.0	3.0×10^{1}	1.0×10^{-1}	3.0
Iridium-192	8.0×10^{1}	2.0×10^{3}	8.0×10^{-1}	2.0×10^{1}	8.0×10^{-2}	2.0
Selenium-75	2.0×10^{2}	5.0×10^{3}	2.0	5.0×10^{1}	2.0×10^{-1}	5.0
Thulium-170	2.0×10^{4}	5.0×10^{5}	2.0×10^{2}	5.0×10^{3}	2.0×10^{1}	5.0×10^{2}
Ytterbium-169	3.0×10^{2}	8.0×10^{3}	3.0	8.0×10^{1}	3.0×10^{-1}	8.0

[a] The primary values to be used are given in TBq. The values in curies are provided for practical usefulness and are rounded after conversion.

TABLE A.2. RECOMMENDED CATEGORIES FOR SOURCES USED IN COMMON PRACTICES FOR RADIOGRAPHY PURPOSES

Category	Source	A/D[a,b]
1	Radioisotope thermoelectric generators Irradiators Teletherapy sources Fixed multibeam teletherapy (gamma knife) sources	$A/D \geq 1000$
2	Industrial gamma radiography sources High/medium dose rate brachytherapy sources	$1000 > A/D \geq 10$
3	Fixed industrial gauges that incorporate high activity sources[c] Well logging gauges	$10 > A/D \geq 1$
4	Low dose rate brachytherapy sources (except eye plaques and permanent implant sources) Industrial gauges that do not incorporate high activity sources Bone densitometers Static eliminators	$1 > A/D \geq 0.01$
5	Low dose rate brachytherapy sources (eye plaques) and permanent implant sources X ray fluorescence devices Electron capture devices Mössbauer spectrometry sources Positron emission tomography test sources	$0.01 > A/D$ and $A >$ exempt[d]

[a] A is the activity of the source in TBq. Factors other than A/D have also been taken into consideration in assigning the sources to a category (see Annex I of Ref. [19]).

[b] This column for A/D can be used to determine the category of a source solely on the basis of the value of A/D. This may be appropriate, for example, if the facilities and activities are not known or are not listed, if sources have a short half-life and/or are unsealed, or if sources are aggregated [19].

[c] Examples are given in the Safety Guide on categorization [19].

[d] Exempt quantities are given in Schedule I of the BSS [2].

DECAYED SOURCES

A.4. If a source decays to a radioactivity level below the appropriate threshold in Table A.1 or below the level that is normally used in common practice (as shown in Table A.2), the regulatory body may allow the operator to re-categorize the source and to reassign it to a lower security level on the basis of the A/D ratio.

AGGREGATION OF SOURCES

A.5. There will be situations in which several radioactive sources are in close proximity, such as in manufacturing processes (e.g. in the same room or building) or in storage facilities (e.g. in the same enclosure). In such circumstances, the regulatory body can aggregate the activity in the sources to determine a situation specific categorization for the purposes of implementing regulatory control measures.

A.6. In situations of this type, the summed activity of the radionuclide should be divided by the appropriate *D* value and the calculated ratio *A*/*D* should be compared with the ratios *A*/*D* given in Table A.2. This allows the set of sources to be categorized on the basis of activity. If sources containing various different radionuclides are aggregated, then the sum of the ratios *A*/*D* should be used in assigning the category, in accordance with the following formula:

$$\text{aggregate } A/D = \sum_n \frac{\sum_i A_{i,n}}{D_n}$$

where

$A_{i,n}$ is the activity of each individual source *i* of radionuclide *n*; and
D_n is the *D* value for radionuclide *n*.

A.7. This calculated aggregate value for *A*/*D* should then be compared with the ratios *A*/*D* given in Table A.2 to determine the appropriate security level for the co-located sources. Additional guidance on the aggregation of the activity of radioactive sources can be found in Ref. [19].

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Annex I

EXAMPLE OF A SAFETY ASSESSMENT

INTRODUCTION

I–1. The operating organization carries out a safety assessment for any source of radiation under its control, to determine what steps are necessary to restrict the exposure of its employees. Both normal working conditions and the potential for accidents are considered in the safety assessment.

I–2. The example safety assessment in the following covers the use of X rays and gamma rays in a purpose-built shielded enclosure for a hypothetical company performing non-destructive testing. The following are considered in the assessment:

(a) Normal operations for the purposes of radiography work within the enclosure;
(b) Possible accident situations and steps to prevent accidents and to limit their consequences;
(c) Control measures to restrict exposures;
(d) Potential exposures and possible doses during normal radiography operations.

Radiography sources

I–3. The operating organization is authorized to use X ray and gamma ray radiography sources in a shielded enclosure. Authorized sources include:

(a) One X ray generator (directional) operated at 250 kV and 4 mA — with a radiation output at 1 m of 4 $Sv \cdot h^{-1}$;
(b) One ^{60}Co source up to a maximum of 925 GBq;
(c) One ^{192}Ir source up to a maximum of 3.7 TBq.

Persons at risk

I–4. Persons at risk include radiographers and other employees working nearby.

Existing measures to control exposures

I–5. The shielded enclosure is fitted with high quality safety systems so that opening the enclosure door during an exposure automatically terminates the X ray exposure or retracts the gamma source to the shielded position. An exposure cannot commence if the enclosure door is open.

I–6. Safety systems and procedures ensure that only one radiation source can be used at any one time. Radiation symbols (trefoils) are displayed on all doors to indicate a possible radiation hazard. The shielded enclosure is fitted with a fixed area radiation monitor plus warning lights and signals to indicate when the exposure is due to commence and when exposure is under way.

I–7. Emergency stop switches are provided in the shielded enclosure. These switches can be operated by anyone inside the radiography enclosure and will stop the X ray generator and retract the gamma source to the shielded position.

I–8. The enclosure is shielded so that maximum dose rates outside at ground level are less than 1 $\mu Sv \cdot h^{-1}$. This means that the maximum annual dose to a person outside the enclosure will be less than 0.25 mSv, assuming a maximum occupancy in the area of 250 hours per year. This estimated dose is considered to be acceptable.

I–9. Safety systems and procedures are in place to prevent access to the roof during radiography work.

POSSIBLE DOSES DUE TO ACCIDENTS

I–10. The following are considered to be foreseeable accident scenarios:

(a) A gamma source failing to retract correctly to its shielded position;
(b) A dropped or detached source (location known);
(c) A missing or stolen source;
(d) Failure of a warning system or safety system, leading to entry to the enclosure during an exposure;
(e) Fire or mechanical damage impairing the shielding of an exposure device or breaching the integrity of a sealed source.

I–11. In each of the above scenarios, the worst foreseeable case is that an individual is exposed close to an unshielded source or an energized X ray generator. Table I–1 gives an indication of the whole body doses that could result.

I–12. Dose rates very close to the radiation sources will be very high:

(a) For the gamma source, the dose to the hands if they were placed at a distance of 5 cm from the source for 5 min would be approximately 11 Gy (for the ^{60}Co source) or 16 Gy (for the ^{192}Ir source). This level of dose would result in severe deterministic effects to the hands.
(b) For the X ray generator, the dose to the hands if they were held close to the window of the X ray generator for 5 min would be approximately 8 Gy (assuming a focus–skin distance of 20 cm). This would result in severe deterministic effects to the hands (radiation burns).

I–13. The operating organization has put in place a number of measures to reduce the likelihood of accidents occurring and to mitigate the consequences if an accident does occur. These measures include:

(a) Periodic training in radiation safety for all relevant staff;
(b) Provision of written procedures to minimize the risk of human error;
(c) Regular maintenance of the X ray generator, exposure device and wind-out equipment;
(d) Frequent checks to confirm the location of radioactive sources;

TABLE I–1. DOSE RATE AT 1 m AND TIME FOR EXPOSURE AT 1 m TO EXCEED A WHOLE BODY DOSE OF 20 mSv FOR THREE DIFFERENT SOURCES

Source (activity)	Dose rate at 1 m ($mSv \cdot h^{-1}$)	Time for exposure at 1 m to exceed a whole body dose of 20 mSv
Co-60 (925 GBq)	325	3.7 min
Ir-192 (3.7 TBq)	480	2.5 min
X ray generator operating at 250 kV and 4 mA	4000	18 s

(e) Regular maintenance of all safety and warning systems, as well as routine checks on their operation;
(f) Provision of permanently installed radiation detectors in the shielded enclosure;
(g) Provision of portable radiation monitoring equipment;
(h) Fire prevention measures;
(i) Provision of detailed emergency plans, regular emergency training and emergency exercises.

CONTROL MEASURES

I–14. The safety assessment described here shows that measures for protection are necessary to restrict exposures. The provision of shielding, the use of safety systems and warning systems, and the following of written procedures are necessary measures for protection in a controlled area. The interior of the enclosure is designated as a controlled area.

I–15. The measures specified in the following will ensure that radiation doses to the radiographers and other persons in the area of the radiography facility will be satisfactorily controlled.

Designated areas

Controlled areas

I–16. The inside of the shielded facility is designated as a controlled area on the basis that special procedures are necessary for controlling exposures and for preventing or limiting the extent of potential exposures. Entry into the controlled area is restricted to authorized persons wearing personal dosimeters.

Supervised areas

I–17. The area immediately outside the enclosure and the corridors are designated as supervised areas. This designation is made on the basis that, although the potential for exposures in these areas is minimal, this situation could change (e.g. in the event of changes in working practices or degradation of the shielding). It is therefore appropriate to keep the situation in these areas under review.

Provisions necessary to restrict exposures

I–18. Detailed local rules are available that specify the procedures to be followed to restrict exposures when carrying out radiography work. Restriction of exposures is also achieved by the use of radiography equipment with fail-to-safe warning systems. Provided that the local rules are adhered to, exposure will be restricted as far as is reasonably achievable.

Arrangements for female employees

I–19. If there is a female employee in the operating organization, she would be advised of the necessity and importance of informing her manager if she were to become pregnant, and appropriate arrangements would be made for the radiation protection of the foetus.

Dose investigation level

I–20. A dose investigation level of 2 mSv per year has been set by management. Provided that all safety systems function properly and all procedures are adhered to, the potential for exposure is small, and this investigation level will not be exceeded. This value serves as a useful management tool and is included in the local rules.

Training and qualifications

I–21. All staff are trained to a level appropriate to understand the nature of the radiation hazards and the importance of following specified procedures. All staff are informed that this is essential to minimize radiation doses and to prevent incidents from occurring or to mitigate the consequences of incidents. All staff are also informed to an appropriate level about national regulatory requirements. The need for refresher training is kept under review by the radiation protection officer. Records are kept of all training conducted. All radiographers have nationally recognized qualifications in industrial radiography techniques and are trained in radiation safety.

Individual dose assessment

I–22. There is a potential for radiography staff to receive high doses in the event of a breach of procedures or an accident. Consequently, all radiography staff are subject to individual radiation monitoring and are issued with thermoluminescent

dosimeters, which are changed every two weeks. Dosimeters are worn during all periods of work and are stored away from radiation.

Health surveillance

I–23. Radiographers undergo annual health reviews with a doctor approved by the regulatory body. Radiographers are entitled to see the results of their health reviews.

Workplace monitoring

I–24. Routine workplace monitoring is carried out to verify the extent of the controlled areas and to monitor the effectiveness of engineered safety systems. Routine monitoring is carried out around controlled areas and supervised areas once per week and on each occasion that a radioactive source is renewed. Special monitoring is carried out if there are any changes in radiography techniques or beam direction. Records of all monitoring are kept in accordance with regulatory requirements.

I–25. In addition, a continuous indication of dose rate is provided by radiation meters installed in the shielded enclosure.

I–26. The dose rate meters are tested annually by a test laboratory. Instrument test certificates are retained by the radiation protection officer.

Accounting for radioactive sources

I–27. All radioactive sources are uniquely identifiable, and their locations are checked and recorded every working day. Records are also kept of all changes of radioactive sources, and all spent sources are returned to their original supplier.

Safety system evaluations

I–28. Restriction of exposures relies heavily on engineered safety systems as control measures. The correct functioning of the safety systems is checked at the start of each shift by the radiographers. Records are kept of these checks.

I–29. All safety systems are also maintained annually by a service contractor, and records are kept.

Annex II

OVERVIEW OF INDUSTRIAL RADIOGRAPHY SOURCES AND EQUIPMENT

II–1. A wide range of exposure devices are commercially available for carrying out industrial radiography. These devices include equipment for performing gamma and X ray radiography. A summary of the general characteristics of this equipment is provided here.

GAMMA RADIOGRAPHY SOURCES AND EQUIPMENT

Sources

II–2. Iridium-192 is the radionuclide most commonly used for industrial radiography. There are also others that can be used, the choice being dependent on the characteristics of the test object material. Source assemblies are specific to the exposure device and consist of a sealed capsule, wire or rod. Table II–1 lists the radionuclides most commonly used and their characteristics.

II–3. Sealed sources are housed inside an exposure device that is appropriate for, and compatible with, the source, source holder or source assembly.

TABLE II–1. RADIONUCLIDES MOST COMMONLY USED IN INDUSTRIAL RADIOGRAPHY AND THEIR CHARACTERISTICS

Radionuclide	Energy	Source output at 1 m ($mSv \cdot h^{-1}$ per 37 GBq)	Half-life	Thickness of steel for which this is typically used (mm)
Co-60	1.17 and 1.33 MeV	13.0	5.3 a	50–120
Ir-192	206–612 keV	4.8	74 d	12–70
Se-75	97–401 keV	2.03	120 d	8–30
Yb-169	63–308 keV	1.25	32 d	4–20
Tm-170	51–84 keV	0.25	128 d	2.5–12.5

Types of exposure device and equipment

General classification of exposure devices

II–4. Exposure devices are classified according to their mobility. Class P and Class M exposure devices are, respectively, portable and mobile, whereas Class F exposure devices are fixed:

(1) *Class P*: Portable exposure devices, designed to be carried by one or more persons. The mass of a Class P exposure device does not exceed 50 kg.
(2) *Class M*: Mobile, but not portable, exposure devices designed to be moved easily by a suitable means provided for the purpose, such as a trolley or cart.
(3) *Class F*: Fixed, installed exposure devices or ones with mobility restricted to the confines of a defined working location, such as a shielded enclosure.

II–5. The three classes of exposure device are generally operated by exposing the source in one of two ways, as described in the following.

Shutter type exposure devices

II–6. In shutter type exposure devices, the source remains inside the exposure device at all times. It is exposed either by opening part of the shielding (the 'shutter') or by moving (e.g. rotating) an inner component in which the source is mounted. The solid angle of the radiation beam is not usually more than 60°, and additional collimation can be used to further limit the beam angle. Exposing the source is done either directly by the use of a handle on the exposure device or by a remote means.

Projection type exposure devices

II–7. In projection type exposure devices, a movable source assembly is physically projected out of the device along a hollow guide tube by means of a wind-out cable. The end of the guide tube is placed in a collimator, to locate the source in the desired position and to limit the beam to the minimum size necessary for the task.

II–8. So-called 'S bend' type exposure devices enable the radiographer to operate the system and to expose the source at a safe distance. S bend type exposure devices provide a higher degree of protection than shutter type devices. For high activity sources, the use of projection type exposure devices is essential to ensure that doses to radiographers are as low as reasonably achievable.

II–9. Some projection type exposure devices use compressed air rather than a wind-out cable to expose the source. Such exposure devices are generally used only as part of a purpose-built shielded enclosure. Systems that rely on air pressure or gravity to return the source to the shielded position may not be designed to fail-to-safe, and some regulatory bodies do not authorize their use.

II–10. Other types of specialized radiography equipment include pipe crawler equipment and equipment used for underwater radiography.

Underwater radiography equipment

II–11. For radiography under water, exposure devices are provided with additional safety features, including:

(a) A depth rating, stating the maximum depth at which the exposure device can safely be used.
(b) Seals that prevent the entry of gas or water into parts of the equipment that that are not designed to withstand them. Equipment that is designed to withstand water and gas has seals that allow water and gas to escape during the ascent to the surface.
(c) A mechanism for enabling equipment to be safely operated while the diver is outside the controlled area.

Pipe crawler equipment

II–12. Pipe crawler equipment is used to radiograph welds on pipelines. The machines carry either an X ray tube assembly or a gamma source on a mobile carriage that crawls along inside the pipe. They are powered either by batteries on the carriage, by an internal combustion engine or by cables trailing from a generator. The crawler is activated and controlled by the radiographer from outside the pipe by using a control source. This normally consists of a low activity ^{137}Cs sealed source mounted in a hand-held device and collimated. Radiation from the control source is received by a detector on the crawler.

II–13. Typically, the control source is moved along the outside of the pipe to prompt the crawler to move in the desired forward or reverse direction. The control source is held against the outside of the pipe to make the crawler stop and wait. An exposure begins automatically about 10 s after the control source is removed from the pipe's surface. Some X ray crawlers are fitted with a low activity radioactive source, to help to identify the crawler's position inside the pipeline.

II–14. The radiography source does not leave the device during the exposure within a pipeline pipe. Most such pipe crawler equipment is designed to fail-to-safe such that, if power is lost, the source is automatically shielded.

II–15. Pipeline crawlers typically do not meet all of the requirements of ISO 3999 [II–1]. Operating organizations will need to ensure that there are appropriate additional safety precautions in place for their safe use.

REFERENCE TO ANNEX II

[II–1] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Radiation Protection — Apparatus for Industrial Gamma Radiography — Specifications for Performance, Design and Tests, ISO 3999:2004, ISO, Geneva (2004).

Annex III

EXAMPLES OF ACCIDENTS IN INDUSTRIAL RADIOGRAPHY

III–1. Throughout the history of industrial radiography, accidents have occurred that have resulted in high radiation doses to workers and the public, causing serious injuries to the exposed persons, sometimes necessitating amputation or even resulting in death. Many other accidents did not result in serious injuries, but had the potential to do so or gave rise to unnecessary radiation exposures.

III–2. An IAEA Safety Report [III–1] provides an overview of a number of accidents involving industrial radiography sources that were reported by regulatory bodies, professional associations and scientific journals. The Safety Report describes the scenarios of accidents in industrial radiography, identifies the primary causes and the lessons to be learned, and provides suggestions to the persons and authorities responsible for protection and safety in industrial radiography. A small number of accidents are described in the following to illustrate the potential hazards associated with sources used in industrial radiography if it is not carried out properly.

FAILURE TO CONNECT A SAFETY SYSTEM

III–3. An X ray unit was being replaced. At the time, the interlock on the enclosure door was disconnected and it was never reconnected. One year later, a radiographer turned on the X ray unit to allow it to warm up prior to making his first exposure. He later entered the radiography enclosure to set his film and to make final adjustments to the position of the item to be radiographed. This work involved locating the beam centre with a plumb bob, which the radiographer held in the beam port with his right thumb. There were no alarms inside the enclosure to show that the X ray unit was activated.

III–4. The radiographer realized that he had been exposed when he returned to the console to start the exposure and found that the beam was already turned on. It is estimated that the radiographer's right thumb was in the beam port for about 5 s, an exposure which resulted in an estimated dose of 3.4 Sv to his thumb and 29 mSv to the whole body. The exposure of the radiographer's thumb resulted in erythema (radiation burns) and blistering.

Initiating event

III–5. Reconnection of the interlock system was not ensured in the commissioning of the new X ray unit.

Contributory factors and prevention

III–6. Procedures need to be put in place to ensure that all safety systems are functional after repair or replacement. The radiographer had not performed daily checks of the interlocks prior to use of the enclosure. Such a check would have alerted the radiographer to the fact that the interlock system was not functioning. A radiation survey during operation would have detected the radiation levels and would have been able to prevent his exposure. The radiographer had ignored the warning signal on the control panel.

DEFEAT OF SAFETY ALARMS

III–7. While performing radiography in a shielded enclosure, a radiographer decided to prop open the enclosure door to allow air to circulate in the enclosure as he changed films and set up for the next exposure. When he did this for the first time, he switched the 'door open' alarm to the 'off' position. This switch also defeated the enclosure radiation alarm.

III–8. In a subsequent exposure, the radiographer failed to retract the 3000 GBq (81 Ci) ^{60}Co source being used. The radiographer entered the enclosure without using a survey meter and while the radiation alarm was defeated. He was not wearing a personal dosimeter. A production worker working with the radiographer also entered the enclosure; he also was not wearing a personal dosimeter.

III–9. The radiographer changed the films, adjusted the source collimator and left the enclosure, together with the production coordinator. When the radiographer attempted to crank the source out to the exposed position, he realized that the source had not been retracted following the previous exposure, and that he and the production worker had been exposed.

III–10. Re-enactment of the incident demonstrated that the radiographer received an estimated dose to his eyes of about 90 mSv and a dose to those portions of the hand with which he had adjusted the source collimator that was in excess of 42.5 Sv. The production worker received an estimated dose to his eyes of 40 mSv.

Initiating event

III–11. The interlock and the radiation alarm for the enclosure were deliberately defeated.

Contributory factors and prevention

III–12. The alarm system needs to be designed so that defeating the door alarm does not defeat the radiation alarm. Operational procedures to verify that the source had been returned to the shielded position and that all the appropriate dosimeters were being worn were not followed. If an alarm had been worn, the radiographer would have been alerted to the high radiation levels. The nature of the production worker's involvement demonstrated the lack of safety culture within the operating organization.

IMPROPER RESPONSE TO MALFUNCTIONING EQUIPMENT

III–13. In 1994, a radiographer was working at night with an exposure device containing 780 GBq (21 Ci) of ^{192}Ir, and he had difficulties in locking it. He saw that his direct reading dosimeter was reading off-scale, but as his survey meter was malfunctioning, no radiation was detected. He struck the locking assembly with a hammer to achieve the locked position, and then left the exposure device on the site unsupervised while returning to the facility to collect another survey meter.

III–14. The radiographer then went back to the site but found that he had the same problem with the locking assembly. His direct reading dosimeter was still reading off-scale and the second survey meter was also not working properly. On returning again to the facility for another survey meter, he inadvertently left his personal thermoluminescent dosimeter behind, and so he continued working on the site without it. The dosimeter showed an exposure of 8.5 mSv, which was probably incurred while the radiographer was originally incorrectly manipulating the locking assembly of the exposure device.

Initiating event

III–15. Difficulties were experienced in locking the exposure device.

Contributory factors and prevention

III–16. The radiographer failed to follow operational safety procedures when the equipment malfunctioned. Specifically, he:

— Attempted to repair the exposure device using unapproved procedures;
— Did not confirm the operability of the survey meter provided;
— Disregarded the off-scale reading of his dosimeter;
— Left the exposure device unattended at the client's site;
— Did not wear a personal dosimeter.

If the radiographer had met any of these requirements, he could have minimized his exposure.

EXPOSURE INSIDE A PIPELINE

III–17. A radiographer had a permit to carry out X ray radiography work on a pipeline at a gas compressor station. A barrier clearly identified the extent of the controlled area, and pre-exposure and exposure warning signals were given before the work commenced.

III–18. Several exposures had already been made and the X ray tube was still energized when the radiographer saw two men emerge from further along the pipeline. Enquiries revealed that the two men also had a permit to work, that they had been inspecting the pipeline internally and that they had crawled through the X ray beam twice while performing their inspections.

III–19. Reconstruction of the incident revealed that the inspectors had each received an estimated dose of 0.2 mSv.

Initiating event

III–20. The event was caused by a lack of coordination of the work to be performed on the site.

Contributory factors and prevention

III–21. The radiographer did not maintain the required control of the area, resulting in the exposure of two individuals. The radiographer needs to obtain all the necessary cooperation and information from the site manager prior to the start

of operations, so as to be able to maintain control during all radiography operations. The required controls (barriers and warning signals) at the access points to the controlled area were not adequately maintained.

DEATHS FROM RADIATION OVEREXPOSURE

III–22. A fatal radiation accident occurred in 1984 in which eight members of the public died from the consequences of overexposure due to a radiography source. An 1100 GBq (30 Ci) ^{192}Ir source became disconnected from the drive cable and was not properly returned to its exposure device.

III–23. Subsequently, the guide tube was disconnected from the exposure device and the source eventually dropped to the ground. A passer-by picked up the small metal cylinder and took it home. Although the exposure device was marked with the radiation symbol (trefoil), the source itself bore no markings.

III–24. The source was lost from March to June 1984 and a total of eight persons, including the person who took the source home, members of his family and relatives, died; the clinical diagnosis was of lung haemorrhage. It was initially thought that the cause of death was poisoning. Only after the last death was it suspected that the deaths might have been caused by radiation.

Initiating event

III–25. The source assembly became disconnected from the drive cable, fell to the ground and remained at the worksite.

Contributory factors and prevention

III–26. No radiation surveys were performed to ensure that the source had been returned to the fully shielded position. Had radiation surveys been carried out, the problem would have been detected and the accident could have been prevented. In addition, the passer-by who picked up the source did not recognize the health hazard associated with it. The consequences of the incident might have been mitigated if the source had had a warning label on it.

FAILURE OF A DEVICE LOCK AFTER IMPROPER MAINTENANCE

III–27. A radiography event was reported that involved an exposure device locking mechanism that became detached from the exposure device. This allowed the 3600 GBq (98 Ci) ^{192}Ir source to be pulled from the exposure device. The incident occurred after midnight, when two radiographers working in low light were performing radiography work.

III–28. The films were taken for development and the radiographer removed his film badge and placed it on his clipboard, thinking that his work had been completed. However, several exposures had to be redone, and for these he forgot to put his film badge back on.

III–29. To move the exposure device from the first to the second location for repeating the exposure, the radiographer took hold of the crank cable in his left hand and lifted the exposure device with his right hand. He took a few steps and the drive cable fell from the exposure device to the ground. He placed the exposure device on a truck tailgate, thinking that the source had also become disconnected. The radiographer picked up the crank cable approximately 100 cm from the end and moved his hand quickly towards the end of the connector. He gripped what he thought was the cable connector and brought it to within 15 cm of his face. When he realized it was actually the source, he dropped it, alerted the other radiographer and ran from the area.

III–30. Re-enactment of the scenario and calculations of the radiation exposure indicated that the radiographer had received an estimated whole body dose and dose to the lenses of his eyes of 6 mSv. A worst case extremity exposure of the fingers was estimated to be 19 Sv.

III–31. The lock insert of the exposure device used is held in place by two roll pins. One pin was missing, and may have been missing for some time, while the second pin was in the exposure device housing but not inside the lock insert. The absence of both pins allowed the lock insert, the spring and the movable insert to be pulled from the lock box. The drive cable was connected to the source assembly. However, when the lock insert was pulled from the lock box, the drive cable pulled the source assembly from the exposure device, thereby exposing the source.

Initiating event

III–32. The roll pins that secure the lock insert were missing.

Contributory factors and prevention

III–33. The radiographer made the assumption that he had a disconnected source. He did not confirm the situation by using a radiation survey meter. Under a proper inspection and maintenance programme, the missing roll pin would have been detected and replaced. Daily inspections may have detected that the lock insert was loose prior to radiography being performed. In addition, the removal of a film badge before concluding radiography work and not using monitoring equipment are violations of regulatory requirements and indicate a lack of safety culture.

INADEQUATE MAINTENANCE CAUSING OVEREXPOSURE

III–34. A radiographer and his assistant were working with a 3000 GBq (80 Ci) ^{192}Ir source. When the exposures were completed, the assistant disassembled the equipment, placed it on the truck and returned to base. Upon arrival, he carried the exposure device from the truck to the storage facility. While placing the exposure device on a shelf, he tilted it and the source assembly fell to the floor. The radiation alarm in the storage facility alerted him to the hazard, and the source was subsequently recovered and safely shielded.

Initiating event

III–35. Investigations showed that the exposure device had not been properly maintained. The spring loaded latch designed to secure the source in the fully shielded position was not working; the latch had become jammed in the unlocked position by an accumulation of dirt. In addition, the radiographer had neither turned the shutter control to the off position nor had he installed the dust cover cap on the front of the exposure device. This combination of circumstances led to the source falling to the floor.

Contributory factors and prevention

III–36. The lock had become jammed in the unlocked position by an accumulation of dirt. In addition to the lack of maintenance, which caused the lock to fail, secondary securing requirements were not met. The shutter control was not turned to the off position and the dust cover cap had not been installed on the front of the exposure device. Had either of these steps been taken, the source could not have dropped out of the exposure device.

REFERENCE TO ANNEX III

[III–1] INTERNATIONAL ATOMIC ENERGY AGENCY, Lessons Learned from Accidents in Industrial Radiography, Safety Reports Series No. 7, IAEA, Vienna (1998).

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