

DS408

Date: 2008-02-28

IAEA SAFETY STANDARDS

for protecting people and the environment

**Status: Approved by RASSC for submission
to Member States
Reviewed in NS-SSCS
Member States comments due by 15 August
2008**

Radiation Safety in Industrial Radiography

DRAFT SAFETY GUIDE

DS408

IAEA

International Atomic Energy Agency

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FOREWORD

Standard Foreword for SG from the DG

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CONTENTS

| | | |
|----|--|----|
| 1. | INTRODUCTION | 1 |
| | BACKGROUND | 1 |
| | OBJECTIVE | 2 |
| | SCOPE 2 | |
| | STRUCTURE | 3 |
| 2. | DUTIES AND RESPONSIBILITIES | 4 |
| | OPERATING ORGANIZATION | 4 |
| | Management of radiation safety and Safety Culture | 4 |
| | Radiation protection programme | 5 |
| | Quality management system..... | 5 |
| | Facilities and resources..... | 5 |
| | Notification to the regulatory body | 5 |
| | Authorization from the regulatory body | 6 |
| | RADIATION PROTECTION OFFICER..... | 7 |
| | QUALIFIED EXPERTS..... | 8 |
| | WORKERS..... | 8 |
| | Radiographers..... | 8 |
| | Radiographers on short-term contracts (itinerant workers)..... | 9 |
| | THE CLIENT | 10 |
| 3. | SAFETY ASSESMENT | 11 |
| | METHODOLOGY | 11 |
| | OUTCOMES | 12 |
| | REVIEWS..... | 12 |
| 4. | RADIATION PROTECTION PROGRAMME..... | 13 |
| | OBJECTIVES AND SCOPE..... | 13 |
| | STRUCTURE AND CONTENT..... | 13 |
| | MANAGEMENT STRUCTURE AND POLICIES | 14 |
| | Assignment of responsibilities for radiation safety | 14 |
| | Programme of education and training | 15 |
| | Local rules and supervision | 15 |
| | Designation of controlled or supervised areas..... | 16 |
| | Programme of workplace monitoring..... | 16 |
| | Arrangements for individual dose monitoring..... | 17 |

| | | |
|----|---|----|
| | Health surveillance programme..... | 17 |
| | Emergency preparedness plans..... | 17 |
| | Periodic reviews and audits of the performance of the RPP | 17 |
| | Quality assurance and process improvement..... | 17 |
| | RECORD OF SAFETY ASSESSMENT | 18 |
| | RADIATION SAFETY COMMITTEE | 18 |
| 5. | TRAINING AND QUALIFICATIONS | 19 |
| | DESIGN OF A TRAINING PROGRAMME..... | 19 |
| | TRAINING COURSE STRUCTURE AND CONTENT..... | 20 |
| | Fundamentals..... | 20 |
| | Principles of radiation protection | 20 |
| | Practical radiation protection..... | 20 |
| | REFRESHER TRAINING | 21 |
| 6. | INDIVIDUAL MONITORING OF WORKERS | 22 |
| | INDIVIDUAL DOSE ASSESSMENT..... | 22 |
| | PERSONAL ALARM MONITORS | 23 |
| | DIRECT READING DOSIMETERS..... | 24 |
| | RECORD KEEPING | 24 |
| | INVESTIGATION OF DOSES..... | 25 |
| | HEALTH SURVEILLANCE | 26 |
| 7. | WORKPLACE MONITORING..... | 27 |
| | PROGRAMME OF MONITORING..... | 27 |
| | SELECTION, MAINTENANCE AND CALIBRATION OF SURVEY METERS..... | 28 |
| 8. | CONTROL OF RADIOACTIVE SOURCES | 30 |
| 9. | SAFETY OF INDUSTRIAL RADIOGRAPHY SOURCES AND EXPOSURE DEVICES..... | 32 |
| | GAMMA RADIOGRAPHY SOURCES AND EXPOSURE DEVICES | 32 |
| | Sealed Radioactive Sources..... | 33 |
| | Exposure Devices | 34 |
| | Ancillary Equipment..... | 36 |
| | Collimators | 37 |
| | Source changers and storage containers | 37 |
| | Inspection and Maintenance | 37 |
| | RADIATION GENERATORS (X RAY AND ELECTRON)..... | 39 |

| | | |
|-----|---|----|
| | Electrical safety | 40 |
| | Cable length..... | 40 |
| | Collimators and beam filters..... | 40 |
| | Control panel | 40 |
| | X ray tube-head | 41 |
| | Flash X ray units..... | 41 |
| | Inspection and Maintenance of x ray equipment..... | 42 |
| 10. | RADIOGRAPHY IN SHIELDED ENCLOSURES..... | 44 |
| | DESIGN AND SHIELDING..... | 44 |
| | CONTROLLED AND SUPERVISED AREAS..... | 45 |
| | SAFETY AND WARNING SYSTEMS FOR GAMMA RADIOGRAPHY..... | 46 |
| | Door Interlocks | 46 |
| | Warning signals | 46 |
| | Emergency buttons or pull-cords..... | 47 |
| | Radiation warning signs | 47 |
| | SAFETY AND WARNING SYSTEMS FOR X-RADIOGRAPHY | 47 |
| | Door Interlocks | 47 |
| | Warning signals | 48 |
| | Emergency buttons or pull-cords..... | 48 |
| | Radiation warning signs | 48 |
| | PROCEDURES FOR RADIOGRAPHY..... | 49 |
| | DECOMMISSIONING | 50 |
| 11. | SITE RADIOGRAPHY | 52 |
| | PREPARATION FOR SITE RADIOGRAPHY..... | 52 |
| | CO-OPERATION WITH THE CLIENT | 52 |
| | DEMARCATING THE BOUNDARY OF CONTROLLED AREA..... | 53 |
| | WARNING SIGNALS | 54 |
| | WARNING NOTICES | 54 |
| | PATROLLING AND MONITORING THE BOUNDARY | 54 |
| | MONITORING..... | 55 |
| | Portable survey meters..... | 55 |
| | Personal dosimeters | 55 |
| | ADDITIONAL PRECAUTIONS FOR SITE GAMMA RADIOGRAPHY | 55 |
| | Equipment..... | 55 |
| | Transient dose rates | 57 |

| | | |
|------------|--|----|
| | Storage of radioactive sources at remote locations | 57 |
| | Completion of work and removal of sources from site | 58 |
| | ADDITIONAL PRECAUTIONS FOR SITE X RADIOGRAPHY INCLUDING USE OF ACCELERATORS | 58 |
| 12. | TRANSPORT OF RADIOACTIVE SOURCES..... | 60 |
| | MOVEMENT WITHIN THE WORK SITE | 60 |
| | TRANSPORT TO ANOTHER SITE | 60 |
| 13. | EMERGENCY PREPAREDNESS AND RESPONSE..... | 62 |
| | DEVELOPMENT OF EMERGENCY PLANS | 63 |
| | TYPES OF EMERGENCIES | 64 |
| | CONTENTS OF A BASIC EMERGENCY PLAN | 65 |
| | EMERGENCY EQUIPMENT | 66 |
| | SPECIFIC EMERGENCY PROCEDURES | 67 |
| | Gamma sources..... | 67 |
| | Radiographer (response initiator)..... | 67 |
| | Radiation Protection Officer (Radiological assessor) | 67 |
| | X ray equipment | 68 |
| | Radiographer | 68 |
| | Radiation Protection Officer (Radiological assessor) | 68 |
| | TRAINING AND EXERCISES | 69 |
| | PERIODIC REVIEWS OF PLANS AND EQUIPMENT..... | 69 |
| | REPORTING..... | 69 |
| | REFERENCES..... | 71 |
| ANNEX I. | EXAMPLE SAFETY ASSESSMENT | 75 |
| ANNEX II. | OVERVIEW OF INDUSTRIAL RADIOGRAPHY SOURCES AND EQUIPMENT | 81 |
| ANNEX III. | IAEA CATEGORIZATION OF RADIOACTIVE SOURCES..... | 85 |
| ANNEX IV. | EXAMPLES OF ACCIDENTS | 89 |

1. INTRODUCTION

BACKGROUND

1.1. The use of ionizing radiation brings many benefits to humankind and one of the longest established industrial applications is the use of radiography for the non-destructive testing (NDT) of items. Industrial radiography provides a means of checking 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 safety of workers and the public and the environment.

1.2. Industrial radiography can be performed in a safe manner that poses a negligible risk. However, experience also shows that emergencies and incidents involving industrial radiography sources have resulted in high doses to workers, sometimes resulting in severe health consequences such as radiation burns and in a few cases death. Members of the public have also been the innocent victims of radiation overexposures when radioactive sources used for industrial radiography were not properly controlled. Contamination of people and the environment have also resulted from corroded or damaged sources. Due to the nature of the work, industrial radiography is often carried out under difficult working conditions, such as in confined spaces, extreme cold or high temperatures. Working under such adverse conditions might result in operational situations in which the principle of keeping doses as low as reasonably achievable is compromised or not met. All of these aspects indicate the need for senior management to promote a safety culture within their organization to ensure that safety comes first.

1.3. This Safety Guide assumes that there is an effective national legislative and regulatory system for radiation safety in place that covers industrial radiography [1, 2]. For the sake of brevity, the term ‘industrial radiography’ is used throughout this Guide to refer to industrial radiography involving sources of ionizing radiation.

1.4. This Safety Guide updates and replaces Safety Reports Series No. 13 ‘Radiation Protection and Safety in Industrial Radiography’ [3].

OBJECTIVE

1.5. The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (the BSS) [4] specify the basic requirements for protection of people against exposure to ionizing radiation and for the safety of radiation sources. The implementation of those requirements will help to ensure that the number of people exposed to radiation and their doses are kept as low as reasonably achievable, and should help to prevent, or mitigate, the consequences of emergencies and incidents. This Safety Guide recommends how industrial radiography should be carried out within the framework of the BSS and other IAEA Safety Standards.

SCOPE

1.6. This Safety Guide provides recommendations for radiation safety in industrial radiography used for non-destructive testing purposes. This includes industrial radiography that utilizes X ray and gamma sources, both inside shielded facilities that have effective engineering controls and outside shielded facilities using mobile sources (site radiography). The guidance in this publication is based on the BSS and other IAEA Safety Standards which are referenced throughout the text. The guidance in this publication is aimed primarily at managers of operating organizations that are authorized to carry out industrial radiography, radiographers, radiation protection officers, and regulators. The guidance may also be of interest to designers and manufacturers of industrial radiography equipment and facilities.

1.7. Recommendations and guidance relating to industrial radiography techniques such as obtaining a good image is provided in another IAEA publication [5].

1.8. The use of gamma radiography underwater and neutron radiography are relatively rare and will require the development of specialized safety assessments and specific procedures. Therefore, the technical requirements for these aspects of radiography are not specifically addressed in this publication, although the general principles, such as provision of adequate shielding and ensuring that radiation doses are kept as low as reasonably achievable should be applied.

1.9. The use of radiation for the inspection of baggage, mail, cargo, vehicles, people, and other such detection purposes is excluded from the scope of this guide.

STRUCTURE

1.10. 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 is given in Sections 3 and 4, and the need for operating organizations to employ trained and qualified personnel is identified in Section 5. Sections 6 and 7 describe how radiation monitoring of workers and the workplace should be carried out. 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 site radiography conditions (Sections 10 and 11), and the safe transport of radioactive sources (Section 12). Preparedness and response to emergencies and incidents involving industrial radiography sources are described in Section 13. An example safety assessment for industrial radiography is given in Annex I, an overview of industrial radiography sources and equipment are given in Annex II and a summary of the IAEA categorization of radioactive sources is given in Annex III.

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2. DUTIES AND RESPONSIBILITIES

2.1. The overall responsibility for radiation safety lies with the operating organization that is authorized to carry out industrial radiography. Specific duties and the day-to-day responsibilities for the safe operation 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 - the client responsible for the premises where the site radiography is carried out. All responsibilities and duties should be agreed to by all relevant parties and identified in writing.

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 technical and organizational measures needed to ensure protection and safety, and compliance with all relevant regulatory and legislative requirements [6]. In some cases it may be appropriate to appoint other people from outside the organization to carry out tasks or actions related to those responsibilities, but the operating organization retains the ultimate responsibility.

2.3. A senior manager should be nominated to have overall responsibility for overseeing radiation safety, and that industrial radiography is carried out in accordance with national regulations and authorizations. Responsibilities for radiation safety are required to be established [4], and they should be agreed to by all relevant parties, and written down. Managers should also ensure that procedures are in place to protect both workers the public, and to ensure that doses are kept as low as reasonably achievable (the ALARA principle). All policies and procedures should be documented and 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 [4]. A good safety culture is promoted by management arrangements and worker attitudes, which interact to foster a safe approach to the performance of the work. Safety culture is not confined to radiation protection; it should also pervade conventional safety. Operating

organizations with good safety culture do not assign blame when incidents happen, they learn from their mistakes, they foster a questioning attitude and they seek continuous improvement in the safety of work processes.

Radiation protection programme

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

Quality management system

2.6. The operating organization should develop, implement, assess and continually improve a quality management system, which defines the responsibilities of all relevant persons and which details the requirements of the organization, personnel and equipment. A quality management programme should be based on national or international standards [8, 9, 10], and should incorporate mechanisms for routine internal inspections and audits.

Facilities and resources

2.7. The operating organization should ensure that suitable facilities and equipment are available to enable radiography to be carried out safely and in accordance with national regulations. In particular, radiography equipment should incorporate all the relevant safety and warning features. An adequate number of radiographers and assistants, should be available and 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

2.8. The operating organization intending to carry out industrial radiography should submit a notification to the regulatory body of the intention to carry out this type of work. This

notification should be made prior to carrying out radiography for the first time, and the details of the notification should be in accordance with national regulations. Some regulatory bodies may require additional information about site radiography on a case by case basis.

Authorization from the regulatory body

2.9. The operating organization will need to apply to the regulatory body for an authorization to acquire, store, and use of radiography sources. Radiography should not commence until the appropriate authorization is received.

2.10. When applying for an authorization, the operator should provide the appropriate documentary evidence to the regulatory body to demonstrate that an adequate level of radiation safety will be provided and maintained. Some regulatory bodies may also require a justification for using ionizing radiation, rather than using alternative technologies for NDT purposes.

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

- Training and qualifications of all relevant staff;
- Technical information about the radiation source(s) and the equipment to be used, including certificates of sources and exposure devices;
- Safety assessment covering the use and storage of the sources;
- Details of the facilities in which the radiation sources will be used (e.g. shielding, interlock systems, warning systems);
- Radiation protection programme (RPP);
- Emergency plans.

RADIATION PROTECTION OFFICER

2.12. The operating organization should appoint at least one employee as a radiation protection officer (RPO) to oversee the day-to-day implementation of the radiation safety programme and to carry out duties required by the programme. The duties of the RPO might include:

- Supervision of industrial radiography operations;
- Maintenance of source accountancy records;
- Inspection and maintenance of engineering controls, safety and warning features;
- Overseeing access controls to controlled areas;
- Establishment and periodic review arrangements for personal dosimetry;
- Supervision of workplace monitoring arrangements;
- Establishments and periodic review of local rules;
- Investigation of higher than normal exposures, and overexposures.

2.13. The number of RPOs to be appointed will be dependent on the size of the operating organization and the frequency and nature of the radiography carried out. In cases where more than one RPO is appointed, it is important that the duties and responsibilities of each be well defined. Even in small organizations consisting of only a few employees, it is essential that someone with adequate knowledge, training and experience be appointed as the RPO. The RPO should be an employee of the company, should have experience of radiography (perhaps as a radiographer) and have a role that permits the close supervision of radiography work. The operating organization should ensure that the RPO is given sufficient time, authority and resources to carry out their duties effectively. The RPO should also be given the authority 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

2.14. 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, testing and maintenance of radiation survey meters, etc. The responsibility for compliance with national regulations cannot be delegated to the qualified expert and must remain the responsibility of the operating organization. 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 requirement is that the qualified expert satisfies the appropriate national qualification or certification criteria.

2.15. The qualified expert is expected to work in close co-operation with the RPO to ensure that all the required duties and tasks are fulfilled.

WORKERS

Radiographers

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

Radiographers should:

- Follow the local rules and any other relevant procedures;
- Properly use radiation monitors;
- Wear their individual dosimeters, at the correct location at all times during radiography and source handling;
- Co-operate with the RPO and qualified expert on all radiation safety issues;
- Participate in any training concerning radiation safety;
- Abstain from any willful action that could put themselves or others in situations that contravene the requirements national regulations.

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

2.18. Good safety performance is a factor that should be incorporated into the daily routine of performing radiography by all personnel so that the job can be performed properly. Safety performance should be a factor by which the safety performance of the whole operating organization is judged.

Radiographers on short-term contracts (itinerant workers)

2.19. Operating organizations that hire self-employed radiographers on a short-term basis need to ensure that those radiographers are provided the same level of 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 moving-on to carry out work for another employer. Such working practices can create specific difficulties with regulatory compliance and hence it is important that the relevant responsibilities of the operating organization and the itinerant radiographer are clearly specified in the contractual arrangements.

2.20. The responsibilities of the operating organization and the itinerant radiographer will depend on the specific requirements of the national regulations. The operating organization will need to clarify with the radiographer the allocation of responsibilities on subjects such as:

- The provision of individual dosimetry and dose record keeping;
- Health assessment arrangements;
- Workplace monitoring arrangements;
- Local rule provision.

2.21. The operating organization should verify that the radiographer has all the appropriate qualifications and training in both radiation safety and industrial radiography techniques, and that all procedures and other relevant materials are provided in the appropriate language.

THE CLIENT

2.22. The client is the organization or person responsible for hiring the operating organization to do the industrial radiography. The client should always use an operating organization that is authorized according to national regulatory requirements for industrial radiography.

2.23. The client should provide the operating organization with sufficient lead-time to plan and to carry-out the work safely and to enable compliance with any advance notifications required by the regulatory body.

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

2.25. The client is responsible for providing 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 needed. The client is also responsible for informing and/or providing any training on site-specific safety issues to the visiting radiographers.

2.26. 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. The procedures for gaining access to the source store should be clearly defined between the client and the operating organization.

3. SAFETY ASSESMENT

3.1. The operating organization should make and document a safety assessment for each radiation source for which they are authorized. The initial safety assessment, sometimes called a 'prior radiological evaluation', is the primary tool for determining which protection measures are needed, and all the parameters that have a bearing on radiation protection and source safety are considered. The safety assessment should be documented and independently reviewed within the operating organization's quality management programme.

3.2. A safety assessment should be carried out before the source is first received at the site or before being used for the first time. The operating organization should plan ahead to ensure that there is sufficient time for the necessary protection and safety measures to be put into place. A new safety assessment is not necessary for the replacement of a source with an identical one. 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 to either confirm that all the relevant protection measures are in place, or to identify any additional measures that should be put in place.

METHODOLOGY

3.3. Industrial radiography sources produce high radiation levels and hence require a comprehensive safety assessment. The safety assessment should take into consideration the radiation risks from routine use of the radiation source(s) plus the probability and magnitude of potential exposures arising from emergencies and incidents. An example safety assessment for industrial radiography is given in Annex I. The safety assessment should include:

- Consideration of the dose rates from both shielded and unshielded radioactive sources and X ray sets;
- Potential doses to radiographers, other workers and the public for a range of scenarios representing normal use and reasonably foreseeable emergencies and incidents;
- Limits and technical conditions for operation of the sources;
- Ways in which structures, systems, components and procedures related to protection or safety might fail or otherwise lead to potential exposures, and the consequences of

such failures;

- Ways in which external factors could affect protection or safety;
- Ways in which operating errors and human factors could affect protection and safety;
- Evaluation of protection and safety implications of any proposed modifications.

OUTCOMES

3.4. The safety assessment provides a basis for decision making in relation to:

- The engineered safety control measures that are required;
- The development of procedures to be followed by the radiographers (the local rules);
- The requirements and procedures for designating controlled and supervised areas;
- Any public protection requirements;
- Information on reasonably foreseeable emergencies and incidents and the measures required to minimize the likelihood of these emergencies and incidents occurring;
- Information on the actions to take to restrict exposures in the event of an emergency or incident occurring (emergency preparedness plans).

REVIEWS

3.5. The safety assessment should be reviewed whenever:

- Safety may be compromised or affected as a result of modifications to the facilities or to the procedures, or a new radiation source, or a source with different radiation characteristics, is acquired;
- Operational experience or the investigation of emergencies and incidents, failures or errors indicates that the current safety measures are invalid; or
- 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 (RPP) is a key factor in the development and maintenance of a safety culture within an organization [7]. The RPP should specify the operating organization's management structure, policies, procedures and organizational arrangements that are in place to control radiation hazards, to optimize radiation protection measures, to reduce or prevent potential exposures, and to mitigate the consequences of emergencies and incidents.

4.2. The RPP should be tailored and scaled to meet the needs of the operating organization, and reflect the complexities and hazards associated with the radiography activities planned to be conducted. It should be based on operating organization's safety assessment and should address both routine and potential exposure situations.

4.3. The elements of an RPP described below are representative of routine radiography operations with X ray and gamma sources. Operating organizations may need to take account of additional measures and programmes to address unique or unusual workplace hazards.

STRUCTURE AND CONTENT

4.4. The RPP should cover the main elements contributing to radiation protection and source safety. The structure and contents of the RPP should be document with an appropriate level of detail. The essential elements of the RPP include:

- Management structure and policies;
- Assignment of individual responsibilities for radiation safety;
- Education and training programme on the nature of the radiation hazards, protection and safety;
- Local rules and supervision;
- Designation of controlled or supervised areas;

- Arrangements for monitoring workers and the workplace, including the acquisition and maintenance of radiation protection instruments;
- Health surveillance programme;
- System for recording and reporting all the relevant information related to the control of exposures, the decisions regarding measures for occupational radiation protection and safety, and the monitoring of individuals;
- Emergency preparedness plans;
- Methods for periodically reviewing and auditing the performance of the RPP;
- Quality assurance and process improvement.

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

MANAGEMENT STRUCTURE AND POLICIES

4.6. The RPP 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 organization chart, should show the names of the senior managers responsible for radiation safety, the names of the various duty holders (e.g. the RPO) and 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 RPP should contain the company policies on radiation safety, and should include a commitment from the management to fostering a safety culture and to keeping radiation doses as low as reasonable achievable.

Assignment of responsibilities for radiation safety

4.8. The responsibilities of each person in the safety structure should be clearly specified. Responsibilities should be assigned to cover the whole life-cycle of sources, from ordering and receipt, use and storage, to their eventual return to supplier (or other possible end-of life

considerations). The posts for which responsibilities are allocated will include the senior managers of the operating organization (who have the primary responsibility for radiation safety), the Radiation Protection Officer, the Qualified Expert, radiographers, and other workers, as described in Section 2.

4.9. For operating organizations carrying out site radiography on a client's premises, some safety requirements will be the responsibility of the client company rather than the operating organization (e.g. the provision of information on site-specific hazards and safety requirements). It is therefore important that at least one person from the industrial radiography organization be given the responsibility to liaise with the client. This liaison process should include the identification of any hazards on site and the exchange of safety information.

Programme of education and training

4.10. The RPP should describe the full scope of the training program in radiation protection and source safety for radiography operations for all employees (See section 5). These include managers, radiographers, trainees, workers who may be incidentally exposed such as cleaners and maintenance staff, and contractors. The RPP should also specify the minimum educational and professional qualifications for all relevant staff – specially the RPO, radiographers and their assistants.

4.11. The requirements for keeping training records should be consistent with national recommendations and should be specified in the RPP.

Local rules and supervision

4.12. Local rules that describe the procedures to be followed when carrying out radiography should be developed and written in a local language. These local rules should cover all procedures associated with radiography where there is the potential for radiation exposure e.g. routine operations, source exchanges, transport, etc (see Sections 10 and 11). The local rules are an important tool in the restriction of radiation doses and they should include sufficient information and guidance to allow the radiographers and other workers to carry out their duties safely.

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 relevant persons, and a copy should be prominently displayed in the workplace. In smaller organizations with limited radiography

work it may be appropriate to have one set of local rules covering all procedures, whereas in larger organizations it might be appropriate to have several sets of specific local rules e.g.: procedures for carrying out radiography in shielded enclosures, procedures for carrying out site radiography, procedures for exchanging gamma sources, etc. Some client organizations might also require specific local rules to be drawn up to cover radiography on their premises.

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

Designation of controlled or supervised areas

4.15. The RPP should describe how controlled¹ and supervised² areas are designated when conducting industrial radiography. Controlled areas are an essential way of restricting exposures in industrial radiography. Supervised areas may sometimes be needed, particularly around fixed radiography facilities. The designation of these areas should be based on the safety assessment and the measured dose rates. Guidance on setting up controlled areas, especially during site radiography, should be provided (see Sections 10 and 11).

Programme of workplace monitoring

4.16. The RPP should describe the programme for the acquisition, calibration, maintenance and testing of equipment to measure radiation dose-rates. The programme for the routine use of the monitoring equipment should be specified and provide information on the required frequency of dose rate measurements around fixed facilities, the monitoring procedures to be followed when carrying out site radiography, the details to be recorded and how long the records should be kept. The RPP should specify that an adequate number of suitable radiation monitors will be made available to the radiographers – for site radiography the minimum is one dose-rate meter for each source in use (see Section 7).

¹ A controlled area is any 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.

² A supervised area is any area not designated as a controlled area but for which occupational exposure conditions are kept under review even though specific protective measures and safety provisions are not normally needed.

4.17. As part of optimizing radiation doses, the RPP should include dose rate reference levels. These are dose rates that are acceptable during specific tasks, such as at controlled area barriers during site radiography and at the operator's position. Such reference levels should be consistent with relevant national guidance and regulations.

Arrangements for individual dose monitoring

4.18. The RPP should specify the types of dosimetry to be used by workers, the period of wear, arrangements for the assessment of dosimeters and dose record keeping. The Radiation Protection Office (RPO) should review the results periodically to identify doses that may be higher than normal (see Section 6).

Health surveillance programme

4.19. The RPP should contain details of the programme for the periodic health surveillance of the radiographers. This will include the requirements for the initial assessment of worker health and ongoing assessment and surveillance requirements. A Qualified Expert should be consulted in the drawing up of the programme and it should be consistent with national regulatory requirements.

Emergency preparedness plans

4.20. The RPP should contain emergency preparedness plans that are to be implemented in the event of an emergency or incident. Plans should be provided to cover all reasonably foreseeable incidents. Guidance on emergency preparedness is provided in Section 13.

Periodic reviews and audits of the performance of the RPP

4.21. As an integral part of the operating organization's quality management program, the RPP should be assessed on a regular basis. This assessment should identify problems that need to be addressed and any modifications that could improve the effectiveness of the RPP.

4.22. A key part of this review process is a routine series of workplace audits, including a description of who will conduct them, their frequency, expectations, reporting of results and follow-up.

Quality assurance and process improvement

4.23. Industrial radiography and associated activities should be carried out in accordance with

an appropriate quality assurance programme. This programme 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 rectified. Management should also ensure that the correct operational procedures are being followed, and the quality assurance programme specifies the relevant checks and audits to be made, and records to be kept. The precise details and contents of the quality assurance programme should take account of any relevant requirements in national legislation.

4.24. The quality assurance programme should include a mechanism for the collection and feedback of lessons learned from emergencies and incidents, and how these lessons can be used to improve safety.

RECORD OF SAFETY ASSESSMENT

4.25. The basis for the RPP is the safety assessment that 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 RPP documentation.

RADIATION SAFETY COMMITTEE

4.26. In medium to large sized radiography companies, a committee should be established for the purpose of regularly reviewing the performance of the RPP. This committee may be dedicated to radiation safety or may have other (conventional) safety responsibilities. The committee should include the senior manager(s) with responsibility for radiation safety, the RPO(s), radiographer(s) and representatives of the workforce. The responsibilities of the radiation safety committee should include:

- Regular reviews of all aspects of the RPP;
- Review reports of occupational radiation doses prepared by the RPO;
- Make recommendations for improvements in the RPP;
- Provide guidance and direction to the RPO in the performance of the RPO's duties;
- Preparation and dissemination of a regular report to all staff about relevant radiation safety issues.

5. TRAINING AND QUALIFICATIONS

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

5.2. Internationally accepted schemes exist for the training and qualification of radiographers in NDT techniques. Some of these schemes may cover only a limited amount of training in radiation safety, and they may need to be supplemented with additional training specifically in radiation protection and source safety. Such additional training is often provided by specialized training organizations, rather than by the operating organization.

DESIGN OF A TRAINING PROGRAMME

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

5.4. Radiography personnel should be classified into different levels of competence based on their training and experience. In some countries these classifications are designated as assistant radiographer (trainee) and radiographer (a person who is fully qualified), or in other countries as Level 1 and Level 2 radiographer.

5.5. Programmes should be established for the different levels of training to correspond to the responsibilities of the radiographer. The training programme should establish the criteria for passing written and practical examinations as well as procedures that must 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 below.

TRAINING COURSE STRUCTURE AND CONTENT

5.6. Each training course should be structured around specific aims and objectives and be tailored to the needs of the target audience. Detailed information on the structure and content of radiation protection training courses for industrial radiographers may be found in ref [11], and a summary of the essential elements for basic training in radiation safety for industrial radiographers is given below.

Fundamentals

Basic radiation concepts

Radiation quantities and units

Radiation detecting instruments

Biological effects of radiation

Principles of radiation protection

System of radiation protection (justification, optimization, dose limits)

Regulatory requirements

Designation of controlled and supervised areas

Dose limits and investigation levels

Practical radiation protection

Source outputs

Effects of time, distance and shielding

Individual monitoring

Work practices to limit doses

Storage of radioactive sources

Radiation Protection Programme

Local Rules

Emergency Plans

Management of radiation protection

Transport of radioactive sources

Emergency preparedness and response

5.7. The training should practical exercises including the rehearsal of emergency plans such as retrieving a jammed source – although actual radioactive sources should never be used in such rehearsals. Training devices are available that use radio-frequency (RF) transmissions to simulate radioactive sources and can be detected using RF detectors which are specially designed to look like a normal dose-rate meter. As an alternative, simple ‘dummy’ sources can be used which look like a radiography ‘pigtail’ but are not radioactive.

REFRESHER TRAINING

5.8. Industrial radiographers 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 radiation protection and safety, 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 national regulations, and should typically be done every 6 months to 2 years. However, changes in regulations or notifications of safety issues should be disseminated by 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 individual industrial radiographers be assessed on a regular basis to ensure that doses are kept as low as reasonable achievable and are below dose limits. An assessment of the doses can also be a possible indicator of good or bad working practices, faulty equipment, or degradation of shielding or engineered safety systems.

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

6.3. Thermoluminescent dosimeter (TLD) and film dosimeter are commonly used – both of which incorporate a passive element that records radiation exposure that is subsequently processed by a specialized dosimetry laboratory to assess the dose. Another type of dosimeter is the electronic personal dosimeter (EPD) which utilizes a solid-state detector to give an immediate read-out of radiation dose (and sometimes dose rate). In some countries and in some situations the EPD is an approved replacement for the TLD or film dosimeter.

6.4. The ultimate choice of which type of dosimeter to use by industrial radiographers should be evaluated by the RPO, possibly in conjunction with a qualified expert in radiation dosimetry. In addition to fulfilling various technical requirements, the choice of dosimeter may also be influenced by availability, cost and robustness.

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

- Dosimeters should be worn by the radiographers at all times when carrying out any work with radiation.
- Dosimeter should be worn on the outside of the clothing, normally at chest or waist

level.

- For TLDs and film dosimeters, the measuring element should be correctly positioned in the dosimeter holder.
- The dosimeter should only be worn by the person to whom it is issued.
- The dosimeter should be worn the correct way (as advised by the dosimetry service).
- Dosimeters can be sensitive and care should be taken to avoid damaging the measuring element of the dosimeter (e.g.: dosimeters may be damaged by water, high temperatures, high pressure, physical damage, etc).
- Dosimeters should not be exposed to radiation when not being worn by the radiographer (e.g.: the dosimeter should be stored in an area away from radiation sources).
- TLDs and film dosimeters should be promptly processed by the dosimetry service at the end of the wear period.
- 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. 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 ear defenders or other safety equipment is being worn). Such additional information can be an important tool in keeping radiation doses as low as reasonably achievable (ALARA), and can help prevent emergencies and incidents. Operating organizations should therefore consider provide personal alarms to all radiographers and assistants, especially if gamma radiography is carried out.

6.7. Important issues in relation to the use of personal alarm monitors:

- Personal alarm monitors should only be used to supplement, not replacement TLDs or

film dosimeters.

- Personal alarm monitors do not replace the need to use dose-rate survey meters (see below)
- Personal alarm monitors should be tested periodically in accordance with national recommendations and/or guidance from the manufacturer.

6.8. In addition to providing an audible or visible alarm, some personal alarm monitors also give a numerical read-out of dose and/or dose rate. These are described below under 'direct reading dosimeters'.

DIRECT READING DOSIMETERS

6.9. Direct reading dosimeters give an instantaneous reading of the dose received and these can be a very useful tool in restricting exposures in industrial radiography. A simple type of direct reading dosimeter is the quartz fibre electroscope (QFE), which is a device that shows accumulated dose via the deflection of an electrically charged fibre on a scale. QFEs have been used widely for many years, but have now been largely superseded by more modern electronic direct reading dosimeters.

6.10. Electronic direct reading dosimeters are also available and they may incorporate an audible and/or visible alarm feature to warn if a preset dose or dose rate value is exceeded. This enables them to be also used as personal alarm monitors.

6.11. Some specific electronic direct reading dosimeters can also be used to replace TLDs or film dosimeters as the main legal 'recording keeping' dosimeter, although this depends upon national regulatory requirements.

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

RECORD KEEPING

6.13. The operating organization should keep records of doses received by radiographers and any other persons that regularly enter controlled areas. These records should contain details of the doses recorded on the dosimeters worn by the workers, and should clearly identify any

doses received during emergencies and incidents or the implementation of emergency procedures from those received during routine work. These dose records are concerned only with the doses recorded on the worker's primary individual dosimeter, and hence are not normally used to also record measured doses from additional devices such as QFEs and direct reading dosimeters.

6.14. Radiographers and other workers subject to individual monitoring should be given access to their own dose records. The operating organization should also make arrangements for the records to be made available the radiation protection officer, the physician responsible for the health surveillance programme, and the regulatory body.

6.15. When a worker changes employment, the operating organization should provide the workers and the new employer with a summary of the worker's dose records. When a worker stops carrying out radiation work, or leaves the organization and does not commence radiation work with another employer, the operating organization should make arrangements for the retention of the workers dose records, either by the operating organization itself or by any other body specified in national regulations. National regulations may specify a duration over which dose records for each worker are to be kept, for example, until the 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 the appropriate confidentiality of the records is maintained.

INVESTIGATION OF DOSES

6.16. 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. An investigation into an overexposure should focus on the causes of the incident that resulted in the overexposure, and any failures in procedures or safety systems that contributed to the incident. The outcome of the investigation should identify the corrective actions that need to be taken to prevent or minimize the likelihood of such an incident occurring again. The operating organization will need to comply with any investigation or reporting requirements specified by the regulatory body.

6.17. An investigation into a dose that exceeds any investigation level specified by the regulatory body should include a review of events leading to the radiation dose and the

working procedures of the workers concerned. The investigation should identify any procedures or facilities that could be modified or changed to reduce radiation exposures and further optimize the work.

HEALTH SURVEILLANCE

6.18. The operational organization should make arrangements for health surveillance in accordance with any national regulatory requirements. Health surveillance is carried out to assess the worker has an adequate level of fitness for the intended tasks and should also assess the worker's psychological suitability for work with radiation sources. Periodic health assessments are also made to ensure the workers' health remains satisfactory.

7. WORKPLACE MONITORING

PROGRAMME OF MONITORING

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

(a) For radiography in shielded enclosures,:

- Around the walls and doors of the enclosure under a range of operating conditions to ensure that an adequate level of shielding is maintained.
- When entering in the enclosure after the completion of every gamma radiography exposure to confirm that the gamma source has been satisfactorily returned to the shielded container.
- Around the gamma source store to ensure that an adequate level of shielding is maintained.

(b) For site radiography:

- Around barriers during an initial test exposure to confirm that the barriers are correctly positioned to restrict exposure and that the controlled area is properly demarcated.
- At the operator position during gamma source wind-out or when an X ray set is energized.
- Around the barriers during routine exposures to confirm that dose rates remain below any values specified by national regulations or guidance.
- At the operator position during gamma source wind-in or X ray set exposure termination.
- Around the gamma source container after every exposure to ensure that the source has fully returned to the shielded position
- Around any source store used on site, to ensure that an adequate level of shielding is provided.
- Around the site on completion of the radiography work to confirm that no gamma sources have been left on the site.

- Around vehicles used to transport gamma sources prior to departure to and from the site.

7.2. The monitoring programme should describe locations to be monitored, frequency of monitoring and record keeping requirements. This information should be included in the local rules and also 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 the workers and regulatory body.

SELECTION, MAINTENANCE AND CALIBRATION OF SURVEY METERS

7.3. Operating organizations should ensure that suitable and a sufficient number of dose rate monitors are made available to the radiographers. While many monitors are suitable for measuring gamma radiation levels, some may not be suitable for accurately measuring low energy X radiation. If the wrong type of monitor is used, this may result in a significant underestimation of the true dose rate. Information and guidance on the suitability of monitors may be obtainable 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. These tests should assess a number of operating characteristics of the radiation monitor, including the response to known dose rates at specific energies, linearity and the behaviour of the meter at very high dose rates. The frequency of the tests and their content should comply with any requirements specified by the regulatory body.

7.5. Routine operational checks should be carried out on the radiation monitors by the radiographers and the RPO e.g.: physical checks to see if the monitor is damaged, battery checks and zeroing of the scale. A simple in-field way of checking whether a monitor responds to radiation is by placing it close to the surface of a gamma exposure container when the source is in its shielded position.

7.6. Account should also be taken of the environmental conditions in which the meters are to be used; some meters are unsuitable for use in very wet or very hot locations and some are not robust enough to withstand heavy use on site. Some industrial sites where site radiography may be carried out may require special types of radiation monitors to be used. For example

some chemical factories may require radiographers to use radiation monitors that minimize the probability of the accidental ignition of flammable fumes or vapours in areas of the plant (these are often called “intrinsically safe” monitors). Some radiation monitors are also affected by radio-frequency (RF) transmissions – so if radiography is to be carried out close to RF generating equipment then it may be necessary to use specially designed RF-shielded radiation monitors.

DRAFT

8. CONTROL OF RADIOACTIVE SOURCES

8.1. Radioactive sources used for industrial radiography can, and have, caused serious accidents [14,15,16,17]. Industrial radiography gamma sources are generally considered to be Category 2 sources according to the IAEA Categorization of Radioactive Sources [18] (see Annex III). Operating organizations should therefore ensure that gamma radiography sources are kept under proper control from when they are first acquired until when they are finally returned to the supplier or dealt with in another safe manner at the end of their working life. 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 (the Code) [19].

8.2. In relation to the security of radioactive sources, paragraph 2.34 of the international basic safety standards [4] requires:

“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 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 body, and when applicable to the relevant Sponsoring Organization, of information regarding any decontrolled, lost, stolen or missing source;
- (b) a source not be transferred unless the receiver possesses a valid authorization; 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 therefore need to ensure that they obtain radioactive sources only from authorized suppliers, and that disused sources are returned to the original supplier or other authorized party. The import and export of radioactive sources should be consistent with the recommendations in the Code of Conduct [19] and its supplementary guidance on import/export controls [20].

8.4. Operating organizations are required to conduct a periodic inventory of sources to confirm they are in their assigned locations and are secure [4]. Sources should be removed

from a source store or moved to another location only by authorized persons who accurately log their name and the date, time and new location of the source(s). These records should be audited by the RPO at least once per month to ensure that all radioactive sources are where they are supposed to be. Containers that incorporate depleted uranium shielding should be included in the accountancy procedures.

8.5. Any suspected loss of control of a radioactive source should be promptly investigated by the operating organization and notified to the regulatory body (and other authority considered to be relevant) if the source is not found within 24 hours (or less time if the loss is confirmed earlier).

8.6. Guidance on security of radioactive sources related to the prevention of malicious acts is available from IAEA [21].

DRAFT

9. SAFETY OF INDUSTRIAL RADIOGRAPHY SOURCES AND EXPOSURE DEVICES

9.1. A wide range of types of radiation sources, exposure devices and ancillary equipment are commercially available for carrying out industrial radiography. Equipment used for radiography should be obtained from a manufacturer that has an established quality management system such as ISO 9001 [8] to ensure that the designed safety features of industrial radiography equipment are reproduced consistently. Operating organization should ensure that information on the safe use of the equipment is available from the supplier, in a major world language understandable to the user.

9.2. Operating organizations should ensure that equipment used for industrial radiography is not modified without a prior assessment of the impact on original design and original safety assessment. This prior assessment should be reviewed by a qualified expert, or the supplier, and it should be discussed with the regulatory body to see whether additional authorizations or approvals are needed.

9.3. Descriptive information on the various types of radiography systems is provided in Annex II, and guidance on safety issues related to the equipment is given below.

GAMMA RADIOGRAPHY SOURCES AND EXPOSURE DEVICES

9.4. Gamma radiography equipment utilizes a high activity sealed source housed in a self-shielded exposure device. The source remains in the shielded exposure device when not in use. The source is exposed by remotely pushing it out of the shielded exposure device (e.g.: by using push/pull wires) directly into a guide tube where it remains for the desired exposure time after which it is wound back into the exposure device.

9.5. Equipment used for gamma radiography typically consists of several components such as a remote wind-out mechanism which is connected to the radiography source (often called a “pigtail”), which is inside a shielded exposure device, which is connected to a guide-tube. The design and operation of these various components are inter-related; therefore, safety should not be compromised by using components that do not meet original design specifications.

Sealed Radioactive Sources

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

- Certified as meeting the requirements of ‘special form’ radioactive material specified in the IAEA Transport Regulations (TS-R-1) [22];
- Designed, manufactured and tested to meet the requirements of the appropriate ISO standard [23] or equivalent national standard;
- Leak-tested in accordance with the appropriate ISO standard (currently ISO 9978 [24]) and have a valid leak-test certificate that is traceable to each individual source.

9.7. Sealed sources used for industrial radiography are normally part of a source assembly (often called a ‘pig-tail’) that is connected to the drive cable in source projection type systems. Source assemblies should be:

- Designed, manufactured and tested to ensure they meet the requirements of the appropriate ISO Standard (ISO 3999 [23]) or an equivalent national standard;
- Compatible with the exposure container, ancillary equipment (such as guide tubes) and any source changer with which they are used.
- Marked in accordance with ISO 361 [25], or as a minimum marked with the radiation trefoil sign and a legend “RADIOACTIVE”. They should also be durably marked with the manufacturer’s serial number.

9.8. The source assembly must be compatible with the specific exposure device it is intended to be used in and have proven testing in accordance with ISO 3999, i.e.: 50,000 cycle endurance test.

9.9. Some manufacturers provide a recommended working life (RWL) for a sealed source. The RWL is based on a number of factors, including the half-life of the source and the construction of the sources capsule, and is an indication of the period of time over which the source is expected to retain its integrity. These manufacturers recommend that work with a

source stops when the age of the source reaches the RWL. Alternatively, a physical assessment of the source condition by a suitably experienced body or expert may be carried out to support continued use. The Regulatory Body may recommend certain tests for continued use after the source reaches its RWL, such as increased frequency of leak tests or assessment by a qualified expert with the appropriate facilities.

Exposure Devices

Projection type exposure devices

9.10. 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. The exposure device should comply with the requirements of ISO 3999 [23], or equivalent standard or national requirements. Meeting this standard ensures that a minimum safety standard has been met and the device and source combination is fit for use in industrial radiography.

9.11. A description of the various types of exposure devices are given in Annex II.

9.12. Most exposure devices also meet the requirements for a Type B(U) transport package as prescribed in the IAEA Transport Regulations [22]. Further guidance on transporting sources is given in Section 12.

Other types of exposure devices

9.13. There are some unique types of exposure devices in use that do not meet ISO 3999 [23] either due to old designs or due to unique applications. Operating organizations should ensure that such devices are not used until a safety assessment has been performed to determine if any additional safety precautions are necessary. Some examples include air actuated devices that expose the source by projecting it out into a guide tube using air (with no control cable connected to the source). Although this results in low dose to the operator, it is possible to project the source into the facility 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.

9.14. Another type of exposure system, which has been used historically, is the “torch” system. This type of equipment should not be used, but a description is given here for completeness. In a ‘torch’ system the radioactive source was mounted at the end of a short rod

which was stored inside a shielded container. To expose the source it was manually removed from its container (on the end of the rod or ‘torch’) and inserted in a collimator attached to the work-piece. Radiographers using this type of equipment were subjected to unacceptably high radiation levels and its use is no longer justified.

Marking and labeling

9.15. Each exposure container should be permanently and clearly labeled with the following details:

- The international ionizing radiation trefoil symbol (25).
- The word ‘RADIOACTIVE’ in letters not less than 10mm in height, together with a brief warning in a local language.
- The chemical symbol(s) and mass number of the radionuclide(s) for which the container is suitable (e.g. ‘Ir-192’, ‘Co-60’).
- The maximum source activity permitted in the container, quoted for each radionuclide for which it is suitable.
- The international standard (ISO 3999 [23]) or equivalent national standard to which the container and its accessories conform.
- The manufacturer’s name, model number and serial number of the container.
- The mass of depleted uranium shielding, if applicable, or the indication ‘Contains depleted uranium’.
- The operator’s name and address.

9.16. Additionally, the container 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; and
- The identity of the source manufacturer.

Second-hand equipment

9.17. Operating organization that acquire “used” or “second-hand” radiography equipment

should ensure the equipment, and any ancillary equipment, meets current safety standards [23] or equivalent. This can be accomplished by having an assessment performed by the manufacturer or other authorized body.

Depleted uranium shielding

9.18. The shielding of many exposure containers incorporates depleted uranium as it is denser than lead. This enables exposure containers to be physically smaller than would be possible with lead shielding alone and allows the package to meet the Type B(U) transport requirements [22]. Depleted uranium is radioactive, which means that even when ‘empty’ (i.e. not containing a radiography source) these types of containers need to be stored safely and subject to accountancy procedures. Operators should therefore establish which of their exposure containers incorporate depleted uranium and ensure that these containers are durably marked to identify this fact. Some regulatory bodies may also require a separate authorization for such containers and eventual disposal should be in a manner authorized by the regulatory body.

Ancillary Equipment

9.19. Ancillary equipment used with the exposure device includes the control housings, guide tubes and collimators. The minimum performance standards for the ancillary equipment are given in ISO 3999 [23], and it is important that the equipment meet the requirements of this standard. Each model of exposure device has its own specific ancillary equipment. The ancillary equipment should therefore be compatible with the specific exposure device and source assembly with which it is intended to be used, otherwise emergencies and incidents may occur.

9.20. If the operating organization intends to mix ancillary equipment and exposure containers from different manufacturers, they should ensure that the design has been proven to comply with the performance standards in ISO 3999 [23].

9.21. 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 controls and guide tubes lengths greater than the manufacturer’s recommendations.

Collimators

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

Source changers and storage containers

9.23. Source changers are used for the safe exchange of old and new industrial radiography sources between the operator's exposure container and the shipment container used by the source supplier (which is normally returned to the supplier after source exchange).

9.24. Storage containers allow for the secure storage of sealed sources when not in use, and prevent unauthorized access.

9.25. Although there are no specific standards for source changers or storage containers, it is recommended that where possible they meet applicable sections of ISO 3999 [23] or equivalent national standards for dose levels and labeling. Source changers should incorporate a system for ensuring that the source is not accidentally withdrawn from the changer when connecting or disconnecting. They should contain a lock or 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 containing sealed sources except when under direct surveillance of an authorized worker.

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

Inspection and Maintenance

General good practice

9.27. In order to ensure continued good operation, gamma radiography equipment (including all ancillary equipment) requires both routine inspection and formal inspection and maintenance to be carried out.

9.28. Maintenance should only be performed by the manufacturer or specifically trained personnel in accordance with the manufacturer's instructions. Replacement parts should be obtained from the manufacturer in order to keep original safety specifications. Any modifications should be approved by the manufacturer or the regulatory body.

9.29. General good practices include keeping equipment clean so that it functions properly. Mud and excess dirt should be washed off after use, as this could potentially restrict movement of the source.

Routine Inspection

9.30. Radiographers should carry out routine inspection before the start of the work shift in order to detect conditions that could lead to an emergency or incident if left uncorrected. Some of the typical checks include:

Inspection of the exposure device

- Fittings and fasteners are tight
- Lock mechanism functions properly
- Radiation levels are normal
- Connection of guide tube and control mechanism are secure
- Verify source assembly connection to drive cable is secure using a No/Go gauge supplied by the manufacturer to check for excessive wear

Inspection of the remote controls

- Fittings tight
- No crushes, kinks or dents
- Freedom of movement of the drive cable

Inspection of the source guide tubes

- Fittings tight
- No crushes, kinks or dents
- Source tips not worn through

9.31. Inspect any additional ancillary equipment being used, (magnetic-stands, vice-grip clamps, collimator attachments, etc)

- Freedom of movement
- Good working condition
- Assure appropriate for use

If performing a source exchange, perform the pre-operational checks:

- Lock assemblies function properly
- Guide/transfer tube connections are secure
- No obstructions in the guide/transfer tubes

Formal Maintenance Program

9.32. The operating organization should set up a program of formal maintenance of the equipment. The program should indicate that only the supplier or specifically trained operators perform this maintenance at the required intervals taking account of use in severe environments, such as sand, dirt or water. The formal maintenance consists of a complete disassembly of the equipment and a detailed inspection of all the components. Where required, worn or damaged parts are replaced and appropriate lubricant is applied.

RADIATION GENERATORS (X RAY AND ELECTRON)

9.33. Radiation generators include X ray equipment and accelerators such as linear accelerators ('linacs') or cyclotrons. Both X ray equipment and cyclotrons are used in both site radiography and static radiography in shielded enclosures, while 'linacs' should only be used in specially designed shielded enclosures.

9.34. Two types of portable X ray tube assemblies (also called tube heads) are available; those for performing panoramic (radial beam) exposures and those for performing directional exposures. The tube assembly is connected by cable to the control panel, which provides the means for activation and operation of the X ray equipment, or for the pre-selection and indication of operating parameters. The dose to the radiographer can be affected by the cable length, X ray tube parameters and the tube assembly.

9.35. Operating organizations should only use radiation generating equipment such as X ray tubes, linear accelerators and cyclotrons, that comply with the following minimum requirements:

Electrical safety

9.36. Electrical safety contributes indirectly to radiation safety, since electrical faults in X ray equipment can result in serious accidents, some with radiological consequences. X ray equipment should conform to national and international electrical requirements [26]. In particular, all metallic items including casings, interconnecting cables, power supply unit (transformer/generator), X ray control equipment, tube assembly, warning signals, other safety devices should be electrically bonded together (“earth bonding”) and connected to earth (grounded). Advice on electrical matters, as well as inspection and testing, should be provided by a qualified electrical engineer or X ray service engineer.

Cable length

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

Collimators and beam filters

9.38. Directional X ray tube assemblies 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

9.39. The control panel should include the following features:

- A label incorporating the radiation warning (trefoil) symbol, a legend indicating that hazardous X rays are emitted when the equipment is operating and a warning label (in a local language) prohibiting unauthorized use.
- 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 X ray ON condition). Key positions should be clearly marked.

- A labelled warning light (preferably fail-safe) which indicates when the X ray equipment is enabled (i.e. ready to emit X rays).
- A separate labelled warning light (preferably fail-safe) which indicates when the X ray equipment is actually emitting X rays.
- A timer that controls the exposure duration, or an X ray ON switch that requires continuous pressure by the radiographer to maintain X ray production.
- Indicators that show the X ray tube potential in kilovolts (kV) and the current in milliamperes (mA) when the X ray beam is ON.
- A clearly labelled way to immediately terminate the generation of radiation.

X ray tube-head

9.40. The X ray tube head should, wherever practicable, be supported in a suitable stand or clamped in position to prevent it from inadvertently moving. Leakage radiation from the tube-head (i.e. leakage that passes through the sides of the tube rather than forward from the beam aperture) should be restricted through good design and construction and should be specified by the X ray tube manufacturer. The penetrating power of leakage radiation depends on the tube voltage and is particularly important when X ray tubes are operated at more than 500 kV. Data on the maximum dose rates due to leakage radiation at the assembly's surface and at 1 m from the tube target are documented by the manufacturer. Typical maximum dose rate values of leakage radiation from commercial assemblies are up to 100 $\mu\text{Sv}\cdot\text{h}^{-1}$ at 1 m from the target.

Flash X ray units

9.41. Some X ray sets emit very short pulses of X 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 low density or very thin wall thickness items. Large, static flash X ray units are sometimes used in shielded facilities where a high output and extremely short exposure time is required. The same precautions that are used for regular X ray equipment should be used along with any additional safety precautions as determined by the safety assessment. It should be noted that most dose rate meters are unsuitable for the measurement of dose rates around 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 dose meters should be used.

Inspection and Maintenance of x ray equipment

General good practice

9.42. In order to ensure continued good operations, 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 qualified expert. Any replacement parts should be obtained from the manufacturer in order to keep original safety specifications.

9.43. Periodic checks that can be made by the operating organization should include:

- Checks for electrical safety including earth bonding.
- Cleaning/replacing any filters in cooling systems.
- Check for X ray leakage from the tube.
- Checks to ensure that all cables are in good condition, with no fraying or exposed wires.
- Tests on electrical insulation of cables.
- Other routine checks and maintenance recommended by the supplier.
- Tests on all interlocks and emergency cut-out switches.
- Tests on all permanently installed radiation detectors inside radiography enclosures, ensuring that this is done without persons inside the enclosure.

Routine inspection

9.44. The routine inspection should be performed at the start of the work shift. This is carried out to detect conditions that could lead to an emergency or incident if left uncorrected. Some of the typical checks include:

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

Formal maintenance

9.45. The operating organization should set up a program of formal maintenance of the equipment. The program should indicate that the supplier or only specifically trained operators perform this maintenance. A program of formal maintenance should be performed at least annually and more frequently if the equipment is used in severe environments, such as excessive dirt, humid conditions or is frequently moved. The formal maintenance consists of a complete inspection and tests of the equipment and a detailed inspection of all the components. Where required, non-functioning or damaged parts are replaced and tested as needed.

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10. RADIOGRAPHY IN SHIELDED ENCLOSURES

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 unauthorized access to the sources, and to prevent or minimize potential exposure of persons who do enter it when the sources are exposed or energized.

10.2. Industrial radiography should be carried out in shielded enclosures whenever it is reasonably practicable. The use of an enclosure offers the benefit of allowing other work in the vicinity to carry on without interruption and allowing radiography to be carried out as required. The use of a correctly designed and constructed enclosure for radiography work is a major factor in keeping radiation doses as low as reasonably achievable.

DESIGN AND SHIELDING

10.3. 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. It is important to plan the design for immediate and foreseeable future needs before commencing construction.

10.4. The design of the shielded enclosure should comprise of an annotated drawing of the installation and its surroundings. The drawing should include dimensions, as well as the thicknesses, densities and types of shielding materials on all sides, above and below the exposure area. Entrances should be identified 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, and the average duration that a person stays in an area). Proper planning of the facility minimizes the cost of the installation and avoids costly remedial work, which may be required if the degree of protection necessary is not achieved.

10.5. Direct radiation exposure and scatter arising from the operation of shielded enclosures should be limited by appropriate shielding. A comprehensive calculation of the required thicknesses requires the use of detailed transmission data for the relevant shielding material, and the assistance of a suitable qualified expert will be needed in the carrying out of these calculations. Guidance on the use of radiation transmission data and the calculations is beyond the scope of this publication.

10.6. 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 scattering

from objects outside the enclosure, e.g. higher ceilings or walls in the vicinity of the enclosure if it is to be constructed inside another building.

10.7. The national regulatory body may specify the criteria to follow when designing an enclosure, including dose reference levels.

10.8. Some openings or penetrations of the shielding will be necessary for personnel entry and exit points; cranes to place and remove heavy objects to be radiographed; pipework; control cables; ventilation and other ducting. These penetration points must be designed with great care to avoid or at least minimize penetration or scattering of radiation. Weaknesses also may occur after a period of wear, shielding damage, movement of shielding or building settlement. Various design techniques should be used to prevent or minimize these weaknesses.

10.9. The design should take account of, and address, the outcomes of the safety assessment. When the design of the shielded enclosure has been established, no subsequent changes that affect radiation safety are to be made unless they are more effective and are authorized or approved by the Regulatory Body or a qualified expert recognized by the Regulatory Body to perform this function.

10.10. All the documents related 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

10.11. Very high dose rates will exist inside an enclosure during radiography, and this area should be designated as a controlled area.

10.12. The shielded enclosure should be designed in such a way that no controlled area has to be designated outside the enclosure. Depending on the situation it might be necessary to designate the area surrounding the shielded enclosure as supervised area.

10.13. An enclosure may not need to be designated as controlled when it is not in use. However, the approach adopted will depend on the requirements of national regulations.

Door Interlocks

10.14. Shielded enclosures should be fitted with suitable locks and/or interlocks on the access doors to ensure that people cannot get inside 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. 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. It is not always possible to install interlock systems of this nature with manually operated gamma exposure devices, and hence it is permissible to instead use a lock on the door, which is locked closed by the radiographer immediately prior to the source exposure.

10.15. 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 when the radiation monitor detects radiation in excess of a pre-set level, although this may not be possible with some manually operated gamma wind-out equipment. 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 must always use a portable meter to confirm the source is fully shielded.

Warning signals

10.16. A pre-warning signal, which may be either visual or audible, should be made immediately prior to a source exposure. This signal should be clearly observable to any person inside or at the entrance to the enclosure and should last sufficiently long to enable persons to vacate the inside of the enclosure. A second visual or audible warning signal should be made while the source is in the exposed position. The pre-warning signal and source exposed warning signal should be clearly distinguishable from each other, and it is essential that both are observable/audible from within the enclosure. Preferably both signals should be installed such that they operate automatically when a source exposure is made. However, it is acceptable if the pre-warning signal is manually generated by the radiographer immediately prior to making the exposure.

Emergency buttons or pull-cords

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

Radiation warning signs

10.18. Clearly visible warning signs that explain the significance of the pre-warning and source exposed signals should be posted at the entrance to, and inside, the enclosure. The signs should incorporate the radiation trefoil and any other information required by the Regulatory Body. The warning text should be written in a language that is understandable for the persons in the areas around the shielded enclosure.

10.19. The warning signs should be made from materials that are durable under the prevailing environmental conditions and should be replaced as necessary.

SAFETY AND WARNING SYSTEMS FOR X-RADIOGRAPHY

10.20. X ray sets are commonly used for carrying out radiography in shielded enclosures. The radiation output of X ray sets is generally several orders of magnitude higher than that of gamma sources and hence it is very important that the safety systems are carefully and correctly installed to prevent inadvertent exposure of radiographers and other workers. X ray sets should normally be integrated into the safety and warning systems of an enclosure, such that it is not possible to operate the X ray set without the safety systems being in operation.

Door Interlocks

10.21. Shielded enclosures should be fitted with suitable interlocks on the access doors to ensure that people cannot gain unauthorized access while an X ray set is generating radiation. An interlock system should be installed to form a mechanical or electrical link between the exposure control system and the door or other points of entry to the shielded enclosure. The

interlock prevents the generation of X rays until the door is closed, and immediately terminates X ray production if the door is opened. Subsequent closing of the door must not automatically re-energize the X ray set. Common interlock systems incorporate electrical switches or captive key systems. It is important that interlock systems 'fail to safe' such that X rays cannot be generated if any component of the interlock system has failed or is broken. Redundancy, diversity and independence of interlocks provide additional levels of safety.

Warning signals

10.22. A pre-warning signal, which may be either visual or audible, should be made immediately prior to the generation of X rays. This signal should be clearly observable to any person inside or at the entrance to the enclosure and should last sufficiently long to enable persons to vacate the inside of the enclosure. A second visual or audible warning signal should be made while X rays are being generated. The pre-warning signal and X rays on warning signal should be clearly distinguishable from each other, and it is essential that both are observable from within the enclosure. They should also be selected so as not to be confused with any other warning signals in use in the area. The signals should be installed such that they operate automatically when an X ray exposure is initiated. The warning signal system should be designed or installed such that X rays cannot be generated in the event of the failure of any component of the system e.g. light bulb failure.

10.23. Notices that clearly explain the significance of the pre-warning and source exposed signals should be posted at the entrance to, and inside, the enclosure.

Emergency buttons or pull-cords

10.24. Emergency stop buttons or pull cords should be installed to enable any person within the shielded enclosure to quickly trigger an alarm and automatically terminate or prevent a radiation exposure. The buttons and pull-cords should be located so that they can be reached without passing through the primary radiation beam, and should be labeled with clear instructions on their use. It should also be possible for persons inside the enclosure to either leave rapidly or shelter behind suitable shielding. The radiographer should be able to terminate the exposure immediately in an emergency.

Radiation warning signs

10.25. Clearly visible warning signs that explain the significance of the pre-warning and

source exposed signals should be posted at the entrance to, and inside, the enclosure. The signs should incorporate the radiation trefoil and any other information required by the Regulatory Body. The warning text should be written in a language that is understandable for the persons in the areas around the shielded enclosure.

10.26. The warning signs should be made from materials that are durable under the prevailing environmental conditions and should be replaced as necessary.

PROCEDURES FOR RADIOGRAPHY

10.27. Radiography in a shielded enclosure should only be performed by competent radiographers that have received appropriate training. Training includes instruction to ensure that the shielded enclosure is used within its design constraints and that all aspects of the facility are maintained to the original specification. The radiographers should also have an understanding of the installed safety and warning systems and the way in which they have to be operated.

10.28. Operating organizations should ensure that written operating procedures and emergency procedures are readily available, in a local language, for radiography work performed in the shielded enclosure.

10.29. No radiography work should be performed in a shielded enclosure other than 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 only be performed after a new safety assessment has been performed and necessary modifications have been made and approved.

10.30. Radiographers should always wear personal dosimeters as specified by the regulatory body. These dosimeters include thermoluminescent dosimeters, personal direct reading dosimeters and personal alarm dosimeters.

10.31. The radiographers should not rely on the installed safety systems to restrict their radiation exposures, and should carry a suitable radiation survey meter whenever they enter the shielded enclosure. In the event of dose rates being measured, the radiographer must immediately vacate the enclosure and seek advice from the RPO.

10.32. A suitable portable survey meter should be available to measure dose rates outside

the enclosure. 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 these values, the work should be terminated and further advice obtained from the RPO.

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

10.34. Collimators and additional shielding should be used as appropriate to minimize potential exposures.

10.35. Before every exposure the radiographer should verify that no persons are inside the shielded enclosure, and should close the doors. Exposures are to be initiated by the radiographer only when the door is closed, all essential shielding is in place, and the safety and warning devices are operational.

10.36. If it is necessary to use the shielded enclosure for purposes not originally covered under the design specification, such as keeping the door open when radiographing unusually long vessels, or using a gamma exposure device in an x-radiography shielded enclosure, then site radiography procedures are to be followed. This includes the setting up of barriers and notices to mark the controlled area, the monitoring of the dose rates around the barriers, and continuous supervision to ensure nobody enters the controlled area.

DECOMMISSIONING

10.37. When an industrial radiography facility is no longer required, and there are no plans to use it again in the foreseeable future, it is essential that the facility is formally decommissioned [27, 28]. All sources of radiation will need to be dealt with in a manner approved by the regulatory body. This may involve the following:

- Gamma sources may, subject to approval from the regulatory body, be transferred to another authorised user. Alternatively the operating organization may return the source to the original supplier, or other action authorized by the regulatory body. Comprehensive records should be kept by the operating organization of all

authorizations for disposal or transfer of the radioactive sources (including any certificates provided by recipients or waste disposal body).

- Exposure devices incorporating depleted uranium should be treated in the same way as gamma sources.
- X ray sets should be made in-operable or, subject to approval from the regulatory body, may be transferred to another authorised user.
- Operating organizations should inform the relevant authorities when all sources of radiation have been removed from the site.
- All radiation warning notices should be removed.
- A comprehensive radiation survey should be made to confirm that no radioactive sources have been left on site.
- Preparation of a final decommissioning report that includes the final radiation survey, and details of transfer or disposal of radiation sources. The final decommissioning report should be submitted to the regulatory body [27, 28].

DRAFT

11. SITE RADIOGRAPHY

11.1. When objects to be radiographed cannot be physically moved into a shielded enclosure it will be necessary to carry out the work under 'site radiography' conditions. This method of radiography is very common, but is also potentially very hazardous because of the absence of engineered safety measures. The location for site radiography may be at the premises of the client, (e.g. in a refinery, an offshore location, or a construction workshop) in urban areas (e.g. at gas pipes, or building constructions), or in the open field (e.g. a pipeline that goes through rural or uninhabited area). Site radiography should only be carried out when it is not practicable to perform radiography in a shielded enclosure because the objects to be radiographed are permanently fixed in location or are too big 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 the previous Section.

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

PREPARATION FOR SITE RADIOGRAPHY

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

11.4. Operating organizations carrying out site radiography should ensure that at least two radiographers, one of whom should be an RPO, are available for each source of radiation.

CO-OPERATION WITH THE CLIENT

11.5. Where radiography 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, e.g. in selecting a suitable location and time for the radiography work to be carried out. The signs, warning signals and alarms to be used in the radiography work should be discussed between by both parties to avoid possible confusion on site. The client should provide information of any radiation detecting systems on the premises as these may be

affected by the radiography work. There may be site-specific hazards that the radiographers need to be aware of, and the client may have a work permit system that has to be followed. A copy of the operating organizations local rules and emergency plans should be given to the client.

11.6. It is very important that the operating organization and the client agree on the planned timescale of the work and the duration over which radiography will be taking place. It is essential that the client provides sufficient time for the work to be carried out to enable the radiographers to work safely and to implement all of the required safety measures.

11.7. The operating organization should discuss with the client the type of radiation source that it is planned to use on the site, and the storage requirements for any radioactive sources that they intend to leave on site overnight (this may also require a separate authorization from the regulatory body)

DEMARCATING THE BOUNDARY OF CONTROLLED AREA

11.8. Site radiography should be carried out in an area designated as a controlled area. The boundary of the controlled area should ensure that doses to people outside the area are below the relevant reference dose levels. The regulatory body may specify maximum permitted dose rates at the barriers during site radiography, typical values being between 7.5 to 20 microsievert per hour. In order to limit the extent of the controlled area collimators should be used where practicable on both X ray sets and gamma radiography sources. Additional local shielding e.g. lead sheets, may be also be appropriate.

11.9. The boundary of the controlled area should be demarcated; when reasonably practicable, this is done by physical means. This may include using existing structures such as walls, using temporary barriers, or cordoning the area with tape. Care should be taken to ensure that access to the controlled area is prevented. This is particularly relevant when radiography is being carried out inside an industrial plant or on a construction site with several floors that can be occupied by people, and where there are ladders, stairways etc. The radiographers should ensure that access is prevented to any areas of high dose rate on floors above and below the work area.

11.10. The remote control or control panel should preferably be outside the controlled area. In any case the radiographers should choose a position to minimize doses to themselves when

initiating and ending an exposure.

WARNING SIGNALS

11.11. Adequate warnings must 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 can be either audible or visible although, in general, pre-warning signals are audible (siren, whistle or bell) while exposure in progress signals are visible lights (e.g. flashing beacons). These signals may be operated manually when radioactive sources are being used, but should operate automatically with X ray units.

11.12. The signals must be clearly observable from all points around the barrier of the controlled area, and hence additional slave signals may need to be incorporated into the warning system.

WARNING NOTICES

11.13. Warning notices should be displayed at the controlled area boundary at suitable positions. The notices should bear the radiation trefoil symbol, warnings and appropriate instructions in the local language. They should also explain the meaning of the exposure pre-warning and warning signals.

PATROLLING AND MONITORING THE BOUNDARY

11.14. Before the start of radiographic work, the area should be cleared of all people except for the radiographers carrying out the work. Prior to initiating an exposure the radiographers should check that there no persons are within the controlled area and that access to the area is prevented.

11.15. The boundary of the controlled area should be clearly visible, well lit and continuously patrolled to ensure that unauthorized people do not enter the area. More than one person will be needed to patrol the area if the boundary is large, or if it cannot be seen from one position.

11.16. A test exposure should be made in order to verify that the dose rates at the boundary are below the relevant limits. The boundary and demarcation of the controlled area should be adjusted if necessary.

MONITORING

Portable survey meters

11.17. For site radiography operations, at least one portable survey meter should be available for each radiography source. Prior to commencing radiography, the meter should be tested, either against a check source or against the exposure container to obtain a reference reading. This will show that the meter is working correctly and will also confirm that the radiographic source is in the shielded position.

11.18. During radiography, the primary objective of monitoring is to determine that the source has returned to the shielded position or that the X ray emission has ceased after each exposure. Exposure devices should always be approached with the portable survey meter switched on since there is the possibility of the radiographic source being stuck in the exposed position or the X ray exposure termination having failed.

Personal dosimeters

11.19. Personal dosimeters such as thermoluminescent dosimeters and direct reading dosimeters should be worn at all times when radiographers are carrying out site radiography. Direct reading dosimeters should be periodically assessed by the radiographers to monitor the doses received during the work.

11.20. Personal alarm dosimeters are particularly useful during site radiography and are a major aid in identifying potential emergencies and incidents. The alarm can be preset to trigger above a specified dose rate and provides an audible, visible or vibrating signal when the radiographer enters an area of high dose rate. Radiographers should wear personal alarm dosimeters during the whole period they may be exposed to ionizing radiation, but they should not consider them to be an alternative to portable survey meters, which should also be used.

ADDITIONAL PRECAUTIONS FOR SITE GAMMA RADIOGRAPHY

Equipment

11.21. Only equipment that is specifically manufactured for gamma radiography should be used. The radiographer should be familiar with all of the equipment, its mode of operation and potential problems. An understanding of the source, its appearance and how it is to be

exposed is particularly important.

11.22. The selection of which radionuclide to use is normally determined by the type and physical size of the object to be radiographed. In operating organizations that have several gamma sources, it is preferable to use the lowest activity source consistent with obtaining the desired radiograph. i.e.: if there is a choice between using a 370 GBq or a 3700 GBq Ir-192 source and if both will produce the desired radiograph, then the lower activity source should be used. 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 operators position; and smaller potential problems if the source becomes jammed. The use of advanced techniques should also be considered, such as image intensification or fast film and screen combinations. Such techniques can play a useful role in reducing doses to the operators.

11.23. Radiography should only to be carried out when the exposure container and all necessary equipment are available and in good working condition. This includes:

- Portable survey meters and personal dosimeters, including spare batteries;
- Guide tubes, control cables and remote control;
- Collimators and local shielding;
- Temporary barriers or tapes;
- Warning notices and signals;
- Emergency kit, including remote source handling tools;
- Other ancillary equipment, such as clamps and positioning aids.

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

- Check the exposure container and exposed ends of cables for damage, wear or dirt. A wear-gauge supplied by the manufacturer should be used;
- Check screws and nuts for tightness and screw threads and springs for damage;
- Confirm that the source locking mechanism works properly;
- Examine the end of the pigtail for wear, damage and proper connection to the control cable; a wear gauge provided by the manufacturer can be used for this purpose;
- Check connections between the exposure container and cables for secure connection;
- Inspect all cables and guide tubes for cuts, breaks, kinks and broken fittings;

- Check the warning label and source tag details for legibility;
- Measure radiation levels close to the exposure container's surface, and confirm that the source is shielded.

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

Transient dose rates

11.26. Transient dose rates outside the boundary during the radiography source wind-out and wind-in operations will be much higher than the dose rates during the actual exposure when the source is in its collimator. Provided the wind-out and wind-in operations occur only briefly, transient dose rates do not present a radiation protection problem.

Storage of radioactive sources at remote locations

11.27. Exposure devices containing radioactive sources may need to be stored on-site overnight or between radiography sessions. The requirement for such storage should be identified during the planning phase, and arrangements made with the site operator for the provision of suitable storage facilities.

11.28. On-site storage facilities may consist of a lockable room, purpose built store or storage pit, but should have the same level of protection as facilities at the operating organization's main base. A suitable storage facility is one that provides protection from the prevailing environmental conditions and also provides an adequate level of security. The store should be resistant to fire in order to minimize the potential for loss of shielding and containment in the event of a fire in the vicinity. The store should be located at a remote distance from corrosive and explosive hazards.

11.29. The store should be made of materials that provide sufficient shielding to reduce dose rates outside the store to below the relevant values specified by the regulatory body.

11.30. The door should be kept locked, and the keys held only by authorized personnel. A warning notice incorporating the international trefoil symbol should be displayed on the door.

Completion of work and removal of sources from site

11.31. On completion of the radiography work, radiographers should use a radiation monitor to ensure that all gamma sources are fully retracted into the shielded container, and have not accidentally been left in the exposed position or have become detached.

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

ADDITIONAL PRECAUTIONS FOR SITE X RADIOGRAPHY INCLUDING USE OF ACCELERATORS

11.33. The procedures discussed in this section are applicable to the use of X ray equipment and techniques, including accelerators and real time radiography. The selection of X ray tube voltage is normally closely linked to the requirements for the quality of the radiograph. The exposure technique (e.g. source internal or external to the workpiece, single wall versus double wall radiographs) should be selected with regard to both good image quality and minimization of dose to persons in the vicinity.

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

- Check for visible damage on all parts of the equipment;
- Check the X ray tube and all exposed ends of the cable for damage, wear, dirt and moisture;
- Check screws and nuts for tightness and screw threads for damage;
- Inspect all cables for cuts, breaks, kinks and broken fittings;
- Check exposure factor settings for legibility.

11.35. If any faults noted, the equipment should not be used until a replacement is provided or a repair is made.

11.36. Accelerators generate very high energy X rays. The dose rate in the main beam of an accelerator can range from 50 mGy min⁻¹ (3 Gy h⁻¹) from a portable accelerator to 4 Gy min⁻¹ (240 Gy h⁻¹) from a mobile accelerator. This means that the dose rate around the apparatus is much higher than during conventional X radiography, and hence more comprehensive control measures are needed to restrict the exposure of radiographers and others in the vicinity to radiation. 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 radiography may not be suitable for use with accelerators.

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12. TRANSPORT OF RADIOACTIVE SOURCES

MOVEMENT WITHIN THE WORK SITE

12.1. When gamma exposure devices and sources are to be moved around a work site, they should remain in the storage facility until they are ready to be moved to their new location. Ancillary equipment should be disconnected from the devices, and all required plugs and caps installed prior to movement. The sources should only be moved in certified packages that are locked and the keys removed. A vehicle or trolley is best used to move the containers and the containers should be securely fastened to the vehicle or trolley, and kept under surveillance for the duration of the movement on the work site.

TRANSPORT TO ANOTHER SITE

12.2. Gamma radiography sources may need to be transported to another location for site radiography. As described above, ancillary equipment should be disconnected from the devices, and all required plugs and caps installed prior to transport. The sources should only be moved in certified packages that are locked and the keys removed. In this case the operating organizations must ensure that the transport complies with regulations based on the IAEA Regulations for the Safe Transport of Radioactive Materials [22] or equivalent national regulations. When applicable, consideration may also need to be given to other international binding documents for specific modes of transport, such as the Technical Instructions for the Safe Transport of Dangerous Goods by Air [29] from the International Civil Aviation Organization (ICAO) and the International Maritime Dangerous Goods (IMDG) Code [30] from the International Maritime Organization (IMO). Regional agreements such as the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) [31], the Agreement of Partial Reach to Facilitate the Transport of Dangerous Goods in some South America countries (MERCOSUR/MERCOSUL) [32] and the European Provisions Concerning the International Carriage of Dangerous Goods by Inland Waterways [33] may also apply.

12.3. The IAEA Transport Regulations [22] assign responsibilities for individuals involved in transport of radioactive material: the consignor (a person, organization or government which prepares a consignment for transport), the carrier (the person, organization or government which undertakes a transport of radioactive material and the consignee (the person, organization or government receiving a consignment). In many site radiography situations, the operating organization will carry out all three roles and hence must satisfy the responsibilities

associated with each role.

12.4. Transport of radioactive material is a complex activity and a comprehensive overview of the relevant requirements is outside the scope of this guide. Guidance on how to apply transport-related requirements is provided by the IAEA Safety Guide Advisory Material for the Safe Transport of Radioactive Material [34].

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13. EMERGENCY PREPAREDNESS AND RESPONSE

13.1. Radiation sources used for industrial radiography have high radiation outputs and are potentially very hazardous. Emergencies and incidents have occurred in the past as a result of operator error or equipment failure, and these have resulted in workers and members of the public receiving high radiation doses [14, 15, 16, 17]. Typical situations which have led to emergencies and incidents include damage to the source or exposure device resulting in a radioactive source being jammed in the exposed position, and the separation of a source pigtail from the wind-out cable resulting in the source being inadvertently left on site.

13.2. Serious radiation over-exposures have occurred when workers physically handled the unshielded source assembly, and when a lost source came into the possession of members of the public. The dose rates in these situations are high enough to injure people in a matter of seconds or minutes and in some cases have even resulted in severe 'radiation burns' leading to the amputation of limbs or other significant health consequences.

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

Radiographers should:

- be properly trained, qualified and be competent;
- follow the local rules and other relevant procedures;
- use survey meters before, after and during every exposure;
- make appropriate inspections of equipment and survey meters prior to use;

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

13.4. Although prevention is the first defence, emergencies can still happen, therefore operating organizations must have pre-prepared emergency plans to be able to respond quickly and safely to mitigate the situation. After the emergency is over, a report should be prepared which includes a critical review of how well the procedures were implemented and what lessons can be learned to prevent similar emergencies and incidents in the future and

how response plans might be improved.

13.5. The section describes potential emergencies and incidents that can happen in industrial radiography and provides recommendations for the development of emergency plans to mitigate the consequences.

DEVELOPMENT OF EMERGENCY PLANS

13.6. The basic obligations and responsibilities for emergency situations are given in the International Basic Safety Standards [4] and in IAEA Safety Requirements [35]. Guidance on developing and implementing emergency plans and a step-by-step method for developing integrated user, local and national emergency response capability is available from IAEA [36].

13.7. The operating organization's safety assessment should identify potential emergencies and incidents that could affect workers or members of the public. This should be used as a basis for preparing emergency plans and procedures for responding to emergencies. A qualified expert may be consulted if needed, when drawing up emergency plans and procedures.

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

- Identification of potential emergencies and incidents during industrial radiography, followed by an evaluation of the associated risks.
- Development of emergency plans and procedures to deal with the identified hazards.
- Specification and acquisition of emergency equipment.
- Training to implement the emergency plan and procedures, including necessary training in the use of emergency equipment.
- Exercises at appropriate intervals to test and evaluate the implementation of the emergency plan.
- Periodic reviews and updates of the emergency plans.

- Reports and notifications of incidents and emergencies.

13.9. Implementation of the emergency plan may also involve response of outside organizations and specialist consultants. The plan should clearly detail the involvement of any outside response, ensuring that the responders are fully aware of and accept their responsibilities. In particular, attention should be paid to an immediate and efficient system for communications between all involved parties. Some regulatory bodies may require operating organization to submit their emergency plans and associated arrangements when applying for an authorization.

TYPES OF EMERGENCIES

13.10. A review of radiography emergencies shows that there are several common events that have occurred historically with industrial radiography sources. Operating organizations should therefore consider the following types of events in their emergency plans, where appropriate.

13.11. For gamma radiography equipment

- Source stuck in the guide tube, collimator, or near the entrance to the exposure container;
- Source becomes disconnected from its drive cable and remains in the guide tube;
- Source is projected out of the end of the guide tube;
- Pipeline crawler becomes stuck in pipe with source exposed;
- Loss of theft of a source.

13.12. For X ray equipment:

- Generation of radiation fails to terminate after the preset time;
- Unintentional energizing of an X Ray tube;
- Radiographer fails to terminate a manually controlled exposure radiation;

- Malfunction of a safety or warning system, including deliberate action to override;
- Other malfunction causing X rays to be generated, other than in a controlled manner;
- Physical damage affecting the shielding or filtration.

CONTENTS OF A BASIC EMERGENCY PLAN

13.13. Operators should ensure that emergency plans address each of the reasonably foreseeable emergency or incident identified in the safety assessment. For industrial radiography emergencies, 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 on scaffolding or in a ditch. As a result the plan should allow for flexibility in the response, with rehearsal on the specifics prior to implementing the plan. The plans should aim to restrict, as far as is reasonably achievable, any exposures that may result from the emergency situation. The plans should include the following:

- (a) Advice on when to implement the emergency plan.
- (b) Prior training needed for workers who will be implementing the procedures.
- (c) Description and availability of emergency response equipment.
- (d) Technical/radiological protection data of relevance to each situation.
- (e) Procedures to be followed at various stages, specific to each identified emergency situation:
 - Initial stage: containment of the situation;
 - Planning stage: plan and rehearse recovery stage;
 - Recovery stage;
 - Post emergency stage, to return situation to normal;
 - Reporting stage: preparation of a report.
- (f) Identification of persons authorized to implement the various stages of the plans.
- (g) Identification of all persons/organizations that may need be contacted at the various stages of the plans, including the necessary telephone, fax, e-mail numbers and addresses.

13.14. In order to minimize exposures and to allow for proper response, the operating organization should as a minimum carry out the following steps:

- Restrict access to the vicinity of the source – ensure that controlled area barriers are in place;
- Ensure that the RPO is notified;
- Avoid panic;
- Move to a safe distance, plan subsequent actions, rehearse the actions without the source and then implement the plans;
- Never enter areas of potentially high, but unknown, dose-rates unless carrying a functional survey meter and, preferably, wearing a personal alarm monitor
- Never touch a radioactive source or allow the hands to come close to it;
- Do not exceed authority or personal expertise;
- Seek assistance from a qualified expert or source supplier if needed.

EMERGENCY EQUIPMENT

13.15. Operators should ensure that all necessary equipment is readily available to deal with all reasonably foreseeable emergency situations. Regular audits should be made to ensure that all emergency equipment is available and is functioning correctly.

13.16. For emergencies and incidents involving gamma radiography sources the following equipment will be needed:

- Appropriate and functioning survey meters to measure both high and low dose-rate.
- Personal alarm and direct reading dosimeters (preferably electronic rather than QFEs).
- Additional personal dosimeters (TLDs/film badges).
- Barrier materials and warning notices.
- Bags of lead shot, spare lead sheet.
- Suitable tool kit and source recovery equipment (long handling tongs, pliers, screwdrivers, bolt cutters, adjustable spanner, hacksaw, torch).
- Emergency shielded storage container or spare source container.
- Communication equipment (e.g., mobile phones, walkie-talkies).
- Spare batteries for survey meters, personal electronic dosimeters, mobile phones and torch.
- Pens, paper, calculator and an incident logbook.
- Equipment manuals.

13.17. If it is suspected that the source capsule is damaged extra care must be taken as radioactive material could leak out of the source, and there is a risk of contaminating people and objects in the vicinity. The detection and measurement of radioactive contamination requires specialized monitoring equipment and expertise which most radiography companies are unlikely to have. If it is suspected or known that a source capsule is ruptured, the operating organization will need to seek advice from an appropriate qualified expert.

SPECIFIC EMERGENCY PROCEDURES

Gamma sources

13.18. This section provides practical guidance for emergencies involving gamma sources used for industrial radiography. Although the steps are listed in the general sequence in which they are to be performed, it is possible that the sequence may need to be adapted at the time of the response. As with all radiological emergencies, the first priority should be protection of persons.

Radiographer (response initiator)

- (a) Recognise that an abnormal situation has occurred that might constitute an emergency.
- (b) Move away from the exposed source and remain calm. Ensure that other radiographers in the vicinity are aware that there is a potential problem.
- (c) Measure the radiation dose rates.
- (d) Establish or re-establish controlled area barriers based on required dose rate reference level.
- (e) Prevent access to the new controlled area.
- (f) Do not leave the controlled area unattended.
- (g) Inform the RPO of the operating organization and the client, and seek assistance.

Radiation Protection Officer (Radiological assessor)

- (a) Plan a specific course of action based on previously established emergency procedures, taking care to minimize doses that may be received by 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 planned activities.
- (c) Implement the planned course of action to the extent that training, equipment and authorizations allow; under no circumstances should the source come into contact with the hands or other parts of the body.
- (d) If the planned course of action is unsuccessful, leave the controlled area and consider the next course of action while continuing surveillance of the controlled area.
- (e) Call technical assistance, if needed, from qualified experts or manufacturers.
- (f) When the emergency is over and the source is safe, assess the doses received and prepare a report.
- (g) Return personal dosimeters to the dosimetry service for exposure assessments.
- (h) Send the damaged or malfunctioning equipment to the manufacturer or qualified expert for a detailed inspection and repair before re-use.
- (i) Notify the regulatory body as required.

X ray equipment

13.19. The following steps should be taken in an abnormal situation involving an X ray tube assembly:

Radiographer

- (a) Recognise that an abnormal situation has occurred 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 X ray tube until details such as position, beam direction, exposure settings (tube voltage, current and time) are recorded.
- (e) Inform the RPO of what has happened.
- (f) Do not use the X-ray equipment until it is examined and repaired by a qualified expert or manufacturer.

Radiation Protection Officer (Radiological assessor)

- (a) Assess the potential doses that could have been received and prepare a report.
- (b) Return personal dosimeters to the dosimetry service for accurate exposure assessment.

(c) Notify the regulatory body as required.

TRAINING AND EXERCISES

13.20. All persons who will participate in implementing the emergency plans should be adequately trained to ensure efficient and effective implementation of their role. This should include both familiarization with and understanding of the plans, together with specific training on actual source recovery procedures and the use of the emergency equipment. Individual workers should only implement parts of the emergency plan for which they have been authorized and trained and for which they have the appropriate equipment. Training provisions should be reviewed periodically to assure continued proficiency of the workers.

13.21. At intervals commensurate with the potential hazard, emergency exercises should be held to test critical components of the emergency plans. Any lessons learned should feed back into reviews of emergency plans.

PERIODIC REVIEWS OF PLANS AND EQUIPMENT

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

- Names of persons, contact details (telephone/fax numbers) etc. are up to date;
- Emergency equipment is readily available and is maintained.

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

REPORTING

13.24. The primary objective of emergency preparedness and response is to mitigate the effects of emergencies and incidents. However, of similar importance is the need to critically review the situations that have occurred so that the lessons learned can provide feedback to improve equipment, maintenance procedures, operating procedures and emergency plans. To this end, a comprehensive report of any emergency or incident is essential.

13.25. Reports of any emergencies and incidents should be prepared by the RPO with the

assistance of qualified experts if needed. The reports should be submitted to senior management and to the regulatory body if required. If the emergency was potentially caused by an equipment malfunction, the supplier should be notified so that the equipment can be evaluated and appropriate actions taken.

13.26. The report should include the following:

- A description of the emergency or incident, giving as much detail as possible concerning the specific equipment involved. This should aim to include model numbers and serial numbers whenever possible.
- Environmental conditions at the time of the emergency or incident, with particular reference as to whether or not these played any significant role in causing the emergency or incident or affecting the outcome.
- The specific cause of the emergencies and incidents.
- Details of actions taken to stabilize the situation and restore conditions back to normal, with special reference to any actions that were noteworthy in both a beneficial and detrimental sense.
- Training and experience of personnel involved.
- An evaluation and summary of doses received by all affected persons.
- Recommendations made with the aim of preventing a similar emergencies and incidents occurring in the future and mitigating the consequences should another similar or related emergency or incident occur.

13.27. A copy of the report should preferably be sent to the regulatory body and should be sent if required by authorization conditions or by national regulations. The lessons learned should be communicated to all involved and any necessary improvements to enhance safety carried out.

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ANNEX I. EXAMPLE SAFETY ASSESSMENT

INTRODUCTION

I-1. The operating organisation should carry out a safety assessment for any source of radiation under its control in order to determine what steps are necessary to restrict the exposure of its employees. The assessment should consider both normal working situations and the potential for accidents.

I-2. The example safety assessment below covers the use of X rays and gamma rays in a purpose-built radiography enclosure at a hypothetical NDT company. The assessment considers:

- Normal operations of work within the enclosure;
- Possible accident situations including and steps to prevent accidents and to limit the consequences;
- Control measures to restrict exposure.

POTENTIAL DOSES DURING NORMAL RADIOGRAPHY OPERATIONS

Radiography sources

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

- One X ray set (directional) operated at 250 kV, 4 mA. Radiation output at 1 m = 4 Sv h^{-1}
- One Cobalt-60 source up to a maximum of 925 GBq, and
- One Iridium-192 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 enclosure is fitted with high quality safety systems so that opening a 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 door is open. Safety systems and procedures ensure that only one radiation source can be operated at any one time.

The enclosure is fitted with warning lights and signals to indicate when the exposure is due to commence and when the exposure is underway.

I-6. Emergency stop switches are provided in the enclosure. These switches can be operated by anyone inside the radiography room and will stop the X ray set and retract the gamma source to the shielded position.

I-7. The enclosure is shielded such that maximum dose rates outside at ground level are less than $1 \mu\text{Sv h}^{-1}$. This means that the annual dose to a person outside the enclosure will be less than 0.25 mSv, assuming a maximum occupancy in the areas of 250 hours per year. This potential dose is considered to be acceptable.

I-8. Safety systems and procedures are in place to prevent access to the roof during radiography.

POTENTIAL DOSES FROM ACCIDENTS

I-9. The following are considered to be reasonably foreseeable accident scenarios:

- Gamma source failing to retract correctly into its shielded position;
- Dropped or detached source (location known);
- Missing or stolen source;
- Failure of a warning or safety system leading to accidental entry to the enclosure during an exposure;
- Fire or mechanical damage impairing the shielding of a source container or the integrity of a sealed source.

I-10. In each of the above scenarios the worst foreseeable case is that an individual is exposed close to an unshielded source or energised X ray set. The table below gives a guide to the whole body doses that could result.

| Source (activity) | Dose rate at 1m (mSv h ⁻¹) | Time at 1m to exceed a whole-body dose of 20 mSv |
|----------------------|---|--|
|----------------------|---|--|

| | | |
|--|-------|-------------|
| Cobalt-60 (925 GBq) | 325 | 3.7 minutes |
| Iridium-192 (3.7 TBq) | 480 | 2.5 minutes |
| X ray set operating at 250 kV, 4 mA | 4,000 | 18 seconds |

I-11. Dose rates very close to the radiation sources will be very high.

- For the gamma sources, the dose to the hands if they were 5 cm from the source for 5 minutes would be approximately 11 Gy (Co-60 source) and 16 Gy (Ir-192 source). This level of dose would result in severe deterministic effects to the hands (radiation ‘burns’).
- For the X ray set, the dose to the hands if they were close to the window of the X ray for 5 minutes would be approximately 8 Gy (assuming a focus-skin distance of 20 cm). This would result in severe deterministic effects to the hands.

I-12. The operating organization has put in place a number of measures to reduce the likelihood of accidents occurring and to mitigate the consequences should an accident occur. These measures include:

- Periodic training in radiation safety for all relevant staff;
- Provision of written procedures to minimise the risk of human error;
- Regular maintenance of the X ray set, source containers and wind-out equipment;
- Frequent checks to confirm the location of radioactive sources;
- Regular maintenance, and routine checks on the operation of all safety and warning systems;
- Provision of a permanently installed radiation detectors in the radiography enclosure;
- Provision of portable radiation monitoring equipment
- Fire prevention measures;
- Detailed emergency plans are provided and regular training/rehearsals carried out.

CONTROL MEASURES

I-13. The safety assessment described above shows that protection measures are needed to restrict exposure (and the shielding, the safety and warning systems and the procedures to follow provide these). The interior of the enclosure is designated as a controlled area.

Designated areas

Controlled areas

I-14. The inside of the shielded facility is designated as a controlled area on the basis that special procedures are needed for controlling normal exposures and for preventing or limiting the extent of potential exposures.

Supervised areas

I-15. The area immediately outside the enclosure and the corridors linking the NDT office with the enclosure are designated as supervised areas. This designation is 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, degradation in shielding etc. It is therefore appropriate to keep the situation in these areas under review.

Restriction of access to controlled areas

I-16. Entry into the controlled area is restricted to authorised persons wearing personal dosimeters.

Actions necessary to restrict exposure

I-17. Detailed local rules are available that specify the procedures to be followed when carrying out radiography. From an equipment viewpoint, restriction of exposure is achieved by the use of radiography equipment with 'fail-to-safety' 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-18. At the present time the company has no female employees working in the NDT department. Should this situation change the employee in question should be informed of the importance of informing her management should she become pregnant and appropriate arrangements would be made to protect the foetus.

Dose Investigation Level

I-19. A dose investigation level of 2 mSv has been set by management. Provided all safety systems and procedures are adhered to, the potential for exposure is small, and this investigation level should not be exceeded. This value serves as a useful management tool and is included in the local rules.

Training and qualifications

I-20. All staff are trained to an appropriate level to understand the nature of the radiation hazards, the importance of following specified procedures, to minimize doses and to prevent accidents from occurring or to mitigate the consequences. All staff are also informed to an appropriate level about national regulatory requirements. The need for refresher training is kept under review by the RPO and records are kept of all training. All radiographers have national recognized qualifications in industrial radiography techniques and are trained in radiation safety.

Individual Dose Assessment

I-21. There is the potential for radiography staff to receive high doses in the event of a breakdown of procedures or in the event of a radiation accident. Consequently all radiography staff are subject to individual radiation monitoring and are issued with TLDs, which are changed every two weeks. Dosimeters are worn during all periods of work and are stored away from radiation in the NDT office.

Health Surveillance

I-22. Radiographers undergo annual health reviews with a doctor approved by the regulatory body. Each radiographer is entitled to see the results of their health review.

Radiation monitoring

I-23. Routine dose-rate monitoring is carried out to verify the extent of controlled areas and to monitor the effectiveness of engineered safety systems. Monitoring is carried out around controlled and supervised areas once per week and on each occasion that a radioactive source is renewed. Additional monitoring is carried out if there are any changes in radiography technique or beam direction. Records of all monitoring are kept for 2 years.

I-24. In addition, a continuous indication of dose rate is provided by radiation meters installed in the shielded enclosure.

I-25. The dose rate meters are tested annually by a test laboratory. Instrument test certificates are retained by the RPO.

Accountancy of radioactive sources

I-26. All radioactive sources are uniquely identifiable and their location is checked and recorded every working day. Records are also kept of all source changes – and all spent sources are returned to their original supplier.

Safety Systems Evaluations

I-27. The restriction of exposure relies heavily on engineered controls so the correct function of these systems is checked at the start of each shift by the radiographers. Records of these checks are kept.

I-28. All safety systems are also maintained annually by a service contractor and records are kept.

CONCLUSIONS

I-29. The measures specified above will ensure that radiation doses to the radiographers and other persons in the area of the radiography facility will be satisfactorily controlled.

ANNEX II. OVERVIEW OF INDUSTRIAL RADIOGRAPHY SOURCES AND EQUIPMENT

II-1. A wide range of exposure devices is commercially available to carry out industrial radiography. The range includes equipment for performing gamma and X ray radiography. A summary of their general characteristics is provided here.

GAMMA RADIOGRAPHY SOURCES AND EQUIPMENT

Sources

II-2. Iridium-192 is the most commonly used radionuclide for industrial radiography, but others can also 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.

| Radionuclide | Energy (MeV) | Source output at 1m (mSvh ⁻¹ per 37 GBq) | Half Life | Typical use for steel of thickness (mm) |
|--------------|------------------|--|-----------|---|
| Cobalt-60 | 1.17 and 1.33 | 13.0 | 5.3 y | 50–100 |
| Ir-192 | 0.2–1.4 | 4.8 | 74 d | 10–70 |
| Se-75 | 0.12–0.97 | 2.03 | 120 d | 4–28 |
| Yb-169 | 0.008–0.31 | 1.25 | 32 d | 2.5–15 |

II-3. Sealed source should be housed inside an exposure container (also called an exposure device or ‘camera’), which is appropriate for, and compatible with, the source, source holder or source assembly.

Types of containers and equipment

General classification of source containers

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

Class P: Portable exposure container, designed to be carried by one or more persons. The mass of a Class P container does not exceed 50 kg.

Class M: Mobile, but not portable, exposure container designed to be moved easily by a suitable means provided for the purpose, for example a trolley or cart.

Class F: Fixed, installed exposure container or one with mobility restricted to the confines of a defined working location, such as a shielded enclosure.

II-5. The three classes of exposure container generally operate by exposing the source in one of two ways, as described below.

Shutter-type exposure container

II-6 In this type of container the source remains inside the container at all times and is exposed either by opening part of the shielding (the “shutter”) or 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 size. Exposing the source is done either directly by the use of a handle on the container or by a remote means.

Projection containers

II-7 In this type of container a moveable source assembly is physically projected out of the shielded exposure container along a hollow guide tube by means of a wind-out cable. The end of the guide tube is placed in a collimator locating the source in the desired position and limiting the beam to the minimum size necessary for the task. So-called ‘S-bend’ type of projection container enables the radiographer to operate the system and expose the source at a

safe distance and hence provide a higher degree of protection than shutter-type containers. For high activity sources, the use of projection containers is essential to ensure that doses to radiographers are as low as reasonably achievable.

II-8 Some projection type containers used compressed air rather than a wind-out cable to expose the source. Such containers are generally only used as part of a purpose built shielded enclosure. Systems that rely on negative air pressures or gravity to return the source to the shielded position may not be designed to fail safe, and hence some regulatory bodies may not authorize their use.

II-9. Other type of specialised equipment includes pipe crawler equipment, equipment used for underwater radiography:

Underwater radiography equipment

II-10. For radiography underwater, exposure containers should be provided with additional safety features, including:

- A depth rating stating the maximum depth at which the container may be safely used.
- Seals that either prevent the entry of gas or water into parts that are not designed to withstand them or, if designed to cope with water and gas, allow them to escape during ascent to the surface.
- A mechanism for enabling equipment to be safely operated while the diver is outside the controlled area.

Pipe crawler equipment

II-11. 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 which crawls along the inside the pipe. They are powered either by batteries on the carriage, an internal combustion engine or trailing cables from a generator. The crawler is activated and controlled by the radiographer from outside the pipe by using a control source which normally consists of a low activity caesium-137 sealed source mounted in a hand-held device and collimated. Radiation from the control source is received by a detector on the crawler. Typically, the control source is moved along the outside of the pipe to initiate 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, and 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 'tell-tale' radioactive source to help to identify the crawler's position in the pipeline.

II-12. The radiography source does not leave the device during the exposure. Most are designed to "fail-to-safe" such that if power is lost, the source is automatically shielded.

II-13 Pipeline crawlers typically do not meet all of the requirements of ISO 3999 [23], but operating organizations will need to ensure that there are appropriate additional safety precautions in place for its safe use.

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ANNEX III. IAEA CATEGORIZATION OF RADIOACTIVE SOURCES

III-1. The IAEA Categorization of Radioactive Sources provides a system of categorization particularly for those sources used in industry, medicine, agriculture, research and education. Its principles can also be applied, where appropriate, in the national context, to sources within military or defence programmes. The Categorization provides an internationally harmonized basis for risk informed decision making and 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.

TABLE III-1. ACTIVITIES OF RADIONUCLIDES THAT MAY BE USED IN INDUSTRIAL RADIOGRAPHY - CORRESPONDING TO THRESHOLDS OF CATEGORIES

| Radionuclide | Category 1 | | Category 2 | | Category 3 | |
|--------------|------------|-------------------|------------|-------------------|------------|-------------------|
| | 1000 x D | | 10 x D | | D | |
| | (TBq) | (Ci) ^a | (TBq) | (Ci) ^a | (TBq) | (Ci) ^a |
| Co-60 | 3.E+01 | 8.E+02 | 3.E-01 | 8.E+00 | 3.E-02 | 8.E-01 |
| Cs-137 | 1.E+02 | 3.E+03 | 1.E+00 | 3.E+01 | 1.E-01 | 3.E+00 |
| Ir-192 | 8.E+01 | 2.E+03 | 8.E-01 | 2.E+01 | 8.E-02 | 2.E+00 |
| Se-75 | 2.E+02 | 5.E+03 | 2.E+00 | 5.E+01 | 2.E-01 | 5.E+00 |
| Tm-170 | 2.E+04 | 5.E+05 | 2.E+02 | 5.E+03 | 2.E+01 | 5.E+02 |
| Yb-169 | 3.E+02 | 8.E+03 | 3.E+00 | 8.E+01 | 3.E-01 | 8.E+00 |

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

TABLE III-2. RECOMMENDED CATEGORIES FOR SOURCES USED IN COMMON PRACTICES

| Category | Source ^a | A/D ^b |
|----------|---|--|
| 1 | Radioisotope thermoelectric generators (RTGs) 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 (except eye plaques and permanent implants) Industrial gauges that do not incorporate high activity sources Bone densitometers Static eliminators | $1 > A/D \geq 0.01$ |
| 5 | Low dose rate brachytherapy eye plaques and permanent implant sources X ray fluorescence (XRF) devices Electron capture devices Mossbauer spectrometry sources Positron emission tomography (PET) check sources | $0.01 > A/D$ and $A >$ exempt ^d |

^a Factors other than A/D alone have been taken into consideration in assigning the sources to a category (see RS-G-1.9 [3], Annex I).

^b This column can be used to determine the category of a source purely on the basis 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 [18].

^c Examples are given in the IAEA Categorization [18]

^d Exempt quantities are given in Schedule I of the BSS [4].

Decayed sources

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

Aggregation of sources

III-3. There will be situations in which 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 may wish to aggregate the activity in the sources to determine a situation specific categorization for the purposes of implementing regulatory control measures. 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 compared with the ratios A/D given in Table III-2, thus allowing the set of sources to be categorized on the basis of activity. If sources with various radionuclides are aggregated, then the sum of the ratios A/D should be used in determining the category, in accordance with the formula:

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

where:

$A_{i,n}$ = activity of each individual source i of radionuclide n .

D_n = D value for radionuclide n .

III-4. This calculated aggregate A/D should then be compared with the ratios A/D given in

Table III-2 to determine the appropriate security level for the collocated sources. Additional information on the aggregation of radioactive sources may be found in IAEA Safety Guide RS-G-1.9 [18].

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ANNEX IV. EXAMPLES OF ACCIDENTS

IV-1. Throughout the history of industrial radiography, accidents have occurred that have resulted in high radiation doses to workers and the public, leading to amputation, causing other injuries that reduced the quality of life of the exposed persons or sometimes resulting in death. Other accidents have occurred that did not result in serious injuries, but either they had the potential to do so, or gave rise to unnecessary radiation exposures.

IV-2. An IAEA Safety Report [17] provides an overview of a large selection of accidents involving industrial radiography sources that were reported by regulatory bodies, professional associations and scientific journals. The Safety Report [17] describes the scenarios of industrial radiography accidents, identifies the primary causes, the lessons learned, and provides suggestions to persons/authorities responsible for radiation protection and safety in industrial radiography. A small selection of those accidents are described below to illustrate the potential hazards if industrial radiography is not carried out properly.

Failure to connect a safety system

IV-3. An X ray unit was replaced. At the time, the interlock on the room door was disconnected and 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 room to set his film and to make final adjustments to the position of the piece to be radiographed. This involved locating the beam centre with a plumb-bob, which had to be held in the beam port with his thumb. There were no alarms inside the room to show that the X ray unit was activated. 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 on. It is estimated that the radiographer's thumb was in the beam port for about 5 seconds, which resulted in an exposure of 3.4 Sv to his right thumb and 29 mSv to the whole body. The exposure of the radiographer's right thumb resulted in erythema (burns) and blistering.

Initiating event

IV-4. Commissioning of the new X ray unit did not ensure reconnection of the interlock system.

Contributory factors and prevention

IV-5. Procedures should be in place to ensure that all safety systems are functional after repair or replacement. No daily check of the interlocks prior to use of the room was performed by the radiographer. Such a check would have alerted the radiographer to the fact that the interlock system was not functioning. A radiation survey during operations would have detected the radiation levels and prevented exposure. The radiographer ignored the warning signal on the control panel.

Defeat of safety alarms

IV-6. While performing radiography in a shielded enclosure, a radiographer decided to prop open the door in order to allow air to circulate in the enclosure as he changed films and set up for the next exposure. When he did this the first time, he switched the door open alarm to the off position. This switch also defeated the enclosure radiation alarm. In a subsequent exposure, the radiographer failed to retract the 3000 GBq (81 Ci) ^{60}Co source being used. He entered the enclosure without using a survey meter and while the radiation alarms were defeated. The radiographer was not wearing a personal dosimeter. A production co-ordinator working with the radiographer also entered the enclosure; he, too, was not wearing a personal dosimeter. The radiographer changed the films, adjusted the source collimator and exited the enclosure, together with the production co-ordinator. When the radiographer attempted to crank the source out to the exposed position, he realized that the source had not been retracted on the previous exposure and that he and the production co-ordinator had been exposed.

IV-7. Re-enactment of the incident demonstrated that the radiographer probably received a dose to his eyes of 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 co-ordinator received a dose to his eyes of 40 mSv.

Initiating event

IV-8. The interlock and radiation alarm for the enclosure were deliberately defeated.

Contributory factors and prevention

IV-9. The alarm system should be designed such that defeating the door alarm does not defeat the radiation alarm. Operational procedures should have been followed to verify that the source had returned to the shielded position, and that all the appropriate dosimeters were worn. Had an alarming device been worn, the radiographer would have been alerted to the

high radiation levels. The production co-ordinator's involvement demonstrates lack of an adequate safety culture within the operating organization.

Improper response to malfunctioning equipment

IV-10. In 1994, a radiographer was working at night with an exposure device containing 780 GBq (21 Ci) of ^{192}Ir and had difficulties in locking it. He saw that his direct reading dosimeter was off-scale, but as his survey meter was also malfunctioning he did not detect any radiation. He struck the locking assembly with a hammer blow to achieve the locked position, and then left the unsupervised exposure device on the site while returning to the facility to collect another survey meter.

IV-11. The radiographer went back to the operation site but found that he had the same problems with the locking assembly. His direct reading dosimeter was still off-scale and the new survey meter was not working properly. On returning to the facility for yet another survey meter he inadvertently left his personal thermoluminescent dosimeter (TLD) behind, and so continued working on the site without it. The TLD showed an overexposure of 8.5 mSv, which was probably received while originally manipulating the lock incorrectly.

Initiating event

IV-12. Difficulties were experienced in locking the exposure device.

Contributory factors and prevention

IV-13. The radiographer failed to follow safe operational 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 his off-scale dosimeter reading; left the device unattended at the client's site; and did not wear a personal dosimeter. If the radiographer had performed any of these required tasks, he could have minimized his exposure.

Exposure inside a pipeline

IV-14. A radiographer had a permit to carry out X ray radiography 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.

IV-15. Several exposures had already been made and the X ray tube was still energized when the radiographer saw two men emerge from a hole further along the pipeline. Enquiries revealed that they also had a permit to work, had been inspecting the pipeline internally, and had crawled through the X ray beam twice while performing their inspections.

IV-16. Reconstruction of the incident revealed that the inspectors had each received a dose of 0.2 mSv.

Initiating event

IV-17. Lack of co-ordination of the work to be performed on the site.

Contributory factors and prevention

IV-18. The radiographer did not maintain the required control of the area, resulting in exposure to two individuals. The radiographer must obtain all the necessary co-operation and information from the site manager prior to the start of operations in order to be able to maintain control during all radiography operations. The required controls (barriers and warning signals) of the access points to the controlled area were not adequately maintained.

Deaths from radiation overexposure

IV-19. A serious accident occurred in 1984 in which eight members of the public died of overexposure from a radiographic source. A 1100 GBq (30 Ci) ^{192}Ir source became disconnected from the drive cable and was not properly returned to its shielded container. Subsequently, the guide tube was disconnected from the exposure device and the source eventually dropped to the ground, where a passer-by picked up the tiny metal cylinder and took it home. Although the exposure device was marked with the international radiation caution symbol, the source itself bore no markings. The source was lost from March to June and a total of eight persons, including the passer-by, members of his family and some relatives, died; the clinical diagnosis was 'lung haemorrhage'. It was initially assumed that the deaths were from poisoning. Only after the last family member had died was it suspected that the deaths might have been caused by radiation.

Initiating event

IV-20. The source assembly became disconnected from the drive cable, fell to the ground and was left at the work site.

Contributory factors and prevention

IV-21. No radiation surveys were performed to ensure that the source had returned to the fully shielded position. Had these been carried out the problem would have been disclosed and the accident may have been prevented. Also, the passer-by did not recognize the potential health hazard associated with the source. The consequences might have been mitigated if the source had had warning signs on it.

Failure of a device lock after improper maintenance

IV-22. A radiography event was reported that involved a camera locking mechanism which came apart 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.

IV-23. The films were taken for development and the radiographer removed his film badge and placed it on his clipboard, thinking his work had been completed. However, several shots had to be retaken, but for these he forgot to put back his film badge.

IV-24. To move the exposure device from the first to the second retake location, 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 the source had disconnected. He picked up the crank-out approximately 100 cm from the end, and moved his hand quickly towards the connector end. He grabbed what he thought was the cable connector and brought it to within 15 cm of his face. When he realized it was the source, he dropped it, alerted his partner and ran from the area.

IV-25. Re-enactment of the scenario and calculation of the radiation exposure indicated that the radiographer had received an estimated whole body and lens of the eye exposure of 6 mSv. A worst case extremity exposure to the fingers was estimated to be 19 Sv.

IV-26. The lock insert of this exposure device is held in place by two roll pins. One was missing, and may have been missing for some time, while the second was in the camera housing but not inside the lock insert. This 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, but when the lock insert was pulled from the lock box the drive cable also pulled the source

assembly from the camera, thereby exposing the source.

Initiating event

IV-27. The roll pins that secure the lock insert were missing.

Contributory factors and prevention

IV-28. The radiographer made the assumption that he had a source disconnect. He did not confirm the actual situation with a radiation survey meter. A proper inspection and maintenance programme would have detected the missing roll pin and had it replaced. Daily inspection may have detected the looseness of the lock insert prior to performing radiography. In addition, removal of a film badge before concluding radiography and not using monitoring equipment are violations of regulatory requirements and indicative of a lack of safety culture.

Inadequate maintenance causes overexposure

IV-29. 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 the shelf, he tilted it and the source assembly fell on to the floor. The radiation alarm in the storage facility alerted him to the hazard, and the source was subsequently recovered and safely shielded.

IV-30. 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 been jammed in the unlocked position by dirt. In addition, the radiographer had neither placed the shutter control in the off position nor had he installed the dust cover cap on the front of the exposure device. A combination of these circumstances led to the source falling on to the floor [6].

Initiating event

IV-31. The lock was jammed in the open position. In addition to the lack of maintenance, which caused the lock to fail, secondary securing requirements were not fulfilled, i.e. turning the shutter to the off position and installing the dust cover cap. Had either of these steps been taken, the source would not have dropped out of the exposure device.