Safety Reports Series

No. 13

RADIATION PROTECTION AND SAFETY IN INDUSTRIAL RADIOGRAPHY

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FOREWORD

The use of ionizing radiation, particularly in medicine and industry, is growing throughout the world, with further expansion likely as technical developments result from research. One of the longest established applications of ionizing radiation is industrial radiography, which uses both X radiation and gamma radiation to investigate the integrity of equipment and structures. Industrial radiography is widespread in almost all Member States. It is indispensable to the quality assurance required in modern engineering practice and features in the work of multinational companies and small businesses alike.

Industrial radiography is extremely versatile. The equipment required is relatively inexpensive and simple to operate. It may be highly portable and capable of being operated by a single worker in a wide range of different conditions, such as at remote construction sites, offshore locations and cross-country pipelines as well as in complex fabrication facilities. The associated hazards demand that safe working practices be developed in order to minimize the potential exposure of radiographers and any other persons who may be in the vicinity of the work. The use of shielded enclosures (fixed facilities), with effective safety devices, significantly reduces any radiation exposures arising from the work.

The demands and rewards of industrial radiography, the ready availability of the essential equipment, the wide range of working conditions and the fact that the techniques employed usually involve the routine manipulation and exposure of powerful gamma emitting sources and X ray machines have all been identified as contributory to the likelihood of accidents. Even in Member States with highly developed regulatory infrastructures, industrial radiographers, on average, receive radiation doses that exceed those of other occupationally exposed workers, and individual industrial radiographers are the most likely group of workers to receive doses approaching relevant dose limits. Radiation protection and safety in industrial radiography is thus of great importance in both developed and developing countries.

This Safety Report summarizes good and current state of the art practices in industrial radiography and provides technical advice on radiation protection and safety. It contains information for Regulatory Authorities, operating organizations, workers, equipment manufacturers and client organizations, with the intention of explaining their responsibilities and means to enhance radiation protection and safety in industrial radiography.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

Radiography is of vital importance in non-destructive testing. Radiography ensures the integrity of equipment and structures such as vessels, pipes, welded joints, castings and other devices. The integrity of this equipment affects not only the safety and quality of the products used by workers, but also the safety and quality of the environment for workers and the public at large.

The safety record of over 40 years of application of ionizing radiation is very good. In particular, radiography can be performed so as to pose a negligible risk on the public and with sufficiently low occupational radiation exposure so as to pose no undue radiological risk on the workers.

However, experience has also shown examples of bad practice. Radiography produces high dose rates so that a person accidentally exposed to the primary beam or in close contact with an unshielded source might within minutes or even seconds receive a dose that results in injury. Also, contamination can result from corroded or damaged sources. Working under adverse conditions might result in operational situations in which the principle of keeping doses as low as reasonably achievable is compromised or not met. These aspects indicate the need to achieve a high degree of professionalism in radiography, using sources and devices designed to the highest standards and working in an environment that promotes a safety culture. This can be accomplished by means of an appropriate national and organizational infrastructure, effective training of workers, compliance with safety requirements, and effective quality control, together with good design, manufacture and maintenance of sources and devices.

1.2. OBJECTIVE

This Safety Report discusses good and current state of the art practices for the safe control and operation of radiography equipment and facilities. It is recognized that this equipment may be used in countries with little or no experience in its use or without a well developed programme of radiation protection.

The purpose is to provide information on safe practices to persons intending to use radiographic techniques and equipment and to governments and their Regulatory Authorities responsible for regulating such use.

1.3. SCOPE

This Safety Report relates to all types of industrial radiography equipment and facilities. It is only concerned with radiation protection and safety and does not deal with how to use radiographic techniques for non-destructive testing.

1.4. STRUCTURE

Radiation protection and safety objectives and considerations are presented in Section 2, while Section 3 describes typical organizational responsibilities for radiation protection and safety in industrial radiography. Sections 4, 5 and 6 deal with types of exposure devices, design and use of shielded enclosures and site radiography, respectively. In Section 7, radiation safety in storage and transport of radiographic sources is discussed, while Section 8 covers emergency response planning in industrial operations.

2. OBJECTIVES OF RADIATION PROTECTION AND SAFETY

The primary aim of radiation protection and safety is to provide appropriate standards of protection and safety for people without unduly limiting the benefits of practices giving rise to exposure.

This primary aim is expressed by the following objectives of radiation protection and safety [1]:

"**Protection objectives:** to prevent the occurrence of deterministic effects in individuals by keeping doses below the relevant threshold and to ensure that all reasonable steps are taken to reduce the occurrence of stochastic effects in the population at present and in the future."

"**Safety objectives:** to protect individuals, society and the environment from harm by establishing and maintaining effective defences against radiological hazards from sources."

Industrial radiography sources emit X rays and gamma radiation which produce dose rates of the order of hundreds of milligrays per hour at one metre. These high dose rates at close distances can cause severe injuries such as radiation burns following exposures of a few seconds. Workers using such sources must achieve the protection objective to prevent doses arising from acute and chronic accidental

exposures and unsafe work practices likely to cause injuries to develop. Safe work practices will protect not only the individual worker but also others in the vicinity and the public from serious consequences arising from the loss or uncontrolled use of these sources.

These radiation protection and safety objectives apply to the design, manufacture or construction, commissioning, operation, maintenance and decommissioning of exposure devices, sealed sources and fixed facilities for industrial radiography. They also apply to the development, application and review of all operating procedures.

The Basic Safety Standards (BSS) are internationally harmonized safety standards that establish requirements for the protection of health and the minimization of danger to life. The BSS establish basic requirements for protection against the risks associated with exposure to ionizing radiation and for the safety of radiation sources that may deliver such exposure, to be fulfilled in all activities involving radiation exposure. They indicate the different aspects that should be covered by an effective radiation protection programme [2]. The present publication provides information on methods that can be used to ensure radiation safety, specifically in industrial radiography.

Adherence to the requirements of the BSS will:

(a) Ensure that during normal operation, maintenance and decommissioning, and in emergency situations, the radiation exposure of both workers and the public is kept as low as reasonably achievable, economic and social factors being taken into account (ALARA principle);
(b) Ensure that during normal operation, maintenance and decommissioning, and in emergency situations, the radiation exposure of both workers and the public is kept below the relevant dose limits given in the BSS;
(c) Ensure that the probability of events giving rise to significant exposures and the magnitude of such exposures are kept as low as reasonably achievable, economic and social factors being taken into account.

Several points or concepts need to be considered in radiation protection programmes:

(a) The sources, exposure devices and facilities need to be of such a design that faultless operation is ensured as effectively as possible. The design includes sufficient safety systems to prevent, detect and respond to deviations from normal operating conditions, considering good engineering practice and concepts of redundancy, diversity, independence and quality assurance. This requires that exposure devices and facilities be routinely reviewed and inspected as part of a formal maintenance programme to ensure continued safe operation. Quality assurance programmes are established to review and assess,

on a regular basis, the effectiveness of the overall radiation protection programme and the implementation of the radiation safety requirements.

(b) A safety culture is fostered and maintained among all workers involved in the industrial radiography industry, from the policy makers and managers of operating organizations to the radiographers. This is necessary to encourage a positive attitude towards protection and safety and to discourage complacency.

(c) Industrial radiography is performed in compliance with dose constraints.

(d) Workers have appropriate qualifications and training.

(e) There are available safe operational procedures for both routine, non-routine and accident situations.

(f) A means is provided for detecting incidents and accidents including those in which human errors were a contributory factor. Exchange of experience and feedback from operational practice is important between all relevant parties involved directly and indirectly in the safe performance of radiographic techniques especially between operators and manufacturers. An analysis of the causes and lessons learned will reduce as far as reasonably practicable the contribution of human error to future accidents and other events that could give rise to exposures. These considerations should be included in the design of radiographic sources and devices, development and conduct of theoretical and practical training programmes, emergency and survey equipment, and in the development of regulatory requirements and operating procedures. The IAEA Safety Report on Accidents in Industrial Radiography and Lessons to be Learned reports previous accidents, the lessons learned from them and the preventive actions [3].

3. ORGANIZATIONAL RESPONSIBILITIES

The safe performance of industrial radiography relies on the people and organizations involved meeting certain responsibilities. These organizations are the Regulatory Authority, the operating organization responsible for carrying out the work, the industrial radiographers, device manufacturers, qualified experts and the client responsible for hiring the operating organization. It is necessary for all concerned to co-operate.

3.1. REGULATORY AUTHORITY

A regulatory system is needed to authorize an application involving sources of radiation to conduct radiography. The consequences of poor or non-existent

regulatory control can be serious and may result in hazardous conditions which may remain undetected for long periods of time.

The general functions of the Regulatory Authority include the following: the development of radiography regulations and guidance; the assessment of applications for permission to conduct radiography; the authorization of such practices and the use of radiation sources associated with them, subject to certain specified conditions; the conduct of periodic inspections to verify compliance with the conditions; and the enforcement of any necessary actions to ensure compliance with the regulations and standards.

3.1.1. Authorization process

Control of practices involving exposure devices for industrial radiography is achieved by means of a system of registration or licensing. The system used will depend on the legislation in place in any given country. The major stages of the authorization process include control of the design, manufacture and distribution of the exposure devices, construction of facilities for industrial radiography, operating programme and decommissioning.

The Regulatory Authority has to assess applications for authorization to conduct the practices. In these cases, the format and content to be submitted by the applicant in support of an authorization application are established by the Regulatory Authority.

Before authorizing the operation of an exposure device or a shielded enclosure (fixed facility), the Regulatory Authority (or qualified expert as allowed by national requirements) needs to complete the review and assessment of:

(a) the exposure device;
(b) the facility, as constructed;
(c) the results of any commissioning tests;
(d) the adequacy of operating and maintenance instructions and procedures and of emergency arrangements;
(e) the records to be kept and the reports to be made both internally and to the Regulatory Authority;
(f) the training and qualifications of personnel and the arrangements for periodic training and for ensuring that adequate standards of training are maintained;
(g) the quality assurance programme for equipment and procedures;
(h) the arrangements for periodic testing, maintenance, auditing and surveillance.

It is also important to ensure at this stage that:

(a) all safety features and warning devices operate correctly;

(b) there is sufficient radiation protection of all persons and the environment;
(c) the operating organization is adequately supplied with information on the correct operation, maintenance and decommissioning of the exposure device and facilities.

The Regulatory Authority gives authorization to the practices and prescribes the conditions or requirements to be attached to the authorization. These requirements may include:

(a) specification of sources and devices, including activity or energy as applicable;
(b) dose constraints or dose rate limitations;
(c) appointment of radiation protection personnel and authorized users;
(d) periodic tests and surveys of radiation protection and safety aspects of the exposure devices and facilities;
(e) record keeping and regular reports to the Regulatory Authority on safety matters such as:
    — operating practices,
    — radiological data, such as the results of radiation surveys, personal dosimetry and medical surveillance,
    — maintenance of exposure devices and fixed facilities,
    — unusual occurrences, such as significant malfunction of a safety system;
(f) modifications to shielded enclosures;
(g) changes in the operating procedures and in the emergency plan, which may have significant consequences for safety;
(h) notifications and reports to the Regulatory Authority on incidents with actual or potential radiological consequences;
(i) places of use and storage; and
(j) arrangements for personnel dosimetry.

When safety related changes are indicated in operational conditions or in equipment and procedures, the Regulatory Authority (or qualified expert as allowed) needs to review and assess the proposed changes before authorizing their implementation.

Whenever the Regulatory Authority becomes aware of a breach of requirements, it may issue a notice to modify, suspend or revoke an operating organization's authorization for work.

Before authorizing the decommissioning of any exposure device or shielded enclosure, the Regulatory Authority may require a review and assessment of the proposed procedures to ensure that radiation safety is maintained.

Whenever the Regulatory Authority becomes aware of improvements in safety related technologies it can modify the operating organization's authorization for work practices, equipment or facilities.

3.1.2. Regulatory inspection

The Regulatory Authority is responsible for ensuring the regulatory inspection of the practices involving exposure devices, to determine whether the applicant is fulfilling the requirements and conditions set out in the pertinent regulations and/or in the authorization.

Inspection programmes confirm that:

(a) shielded enclosures are constructed and exposure devices are manufactured in compliance with authorizations;
(b) all safety systems and components of shielded enclosures and exposure devices are of the required quality;
(c) personnel are trained and competent to operate the exposure devices safely;
(d) approved operational procedures are being followed;
(e) exposure devices and shielded enclosures are appropriately surveyed and maintained;
(f) sources are sealed and leak free;
(g) dosimetric and medical surveillance of the workers are carried out correctly;
(h) the response to incidents follows the agreed emergency plan or regulatory requirements;
(i) exposure devices and shielded enclosures are maintained in a safe and secure condition at the end of use or are decommissioned safely;
(j) the source inventory is properly maintained.

In addition to routine regulatory inspection activities, the Regulatory Authority needs to ensure that inspection and immediate investigation of events and incidents are carried out.

Regulatory inspections are not meant to take away or limit the responsibility of the operating organization.

3.1.3. Enforcement

The Regulatory Authority has powers to enforce compliance with the relevant regulations and authorizations, including the powers to take samples, make measurements and require an operating organization to modify or correct any aspect of a procedure, practice, system, structure or component as necessary to ensure safety. The Regulatory Authority has the power to require an operating organization to cease operation, as necessary and reasonable, to ensure safety.

The severity of the actions of the Regulatory Authority depends on the hazards and risks caused by the deviations or violations. In many cases a written notice or directive to the responsible organization may be sufficient. In the event of chronic or

extremely serious deviations, activities may be curtailed through suspension or revocation of the authorization.

3.1.4. Emergency

The responsibilities of the Regulatory Authority in the implementation of emergency plans [2] vary according to the type of accident and national requirements. The primary responsibility resides with the operating organization. Simple incidents may be resolved by this organization and only require notification to the Regulatory Authority in routine reports or inspections, as defined by the Regulatory Authority.

In view of the diversity of the events that might occur, the Regulatory Authority needs to draw up emergency plans which are general in nature and include the following activities:

— assessment and projection of off-site radiological consequences;
— maintenance of close contact with the local emergency organizations;
— assisting the operating organization in carrying out the emergency response;
— identification of potential medical assistance.

The Regulatory Authority or qualified expert may provide guidance to the operating organization on how to prepare the emergency plan, which is a prerequisite of any licensing or authorization procedure. As a minimum, emergency plans cover events with the greatest potential for exposure as described in Section 8.1.

Emergency notification by the operating organization is required by the Regulatory Authority. The Regulatory Authority has to be able to receive the emergency notification and to provide an adequate response to the emergency.

The Regulatory Authority requires that, in the emergency response, radiological surveys of areas be carried out as appropriate and doses be assessed.

In the post-emergency phase, the Regulatory Authority requires a report of investigation into the causes of the emergency, its consequences, including a full assessment of the doses and corrective actions taken to prevent a recurrence. The Regulatory Authority evaluates the extent to which the emergency plan was implemented and its effectiveness in order to determine whether the plan requires modification.

Much can be learned from previous experience of emergency situations and their resolution. The Regulatory Authority may be in the best position to collate emergency case histories. These accounts are reviewed periodically so that future accidents may be prevented and informed responses are available to deal with future emergencies. The publication of emergency case history reviews helps to alert the international community to specific problems and improved solutions developed from experience.

3.2. THE OPERATING ORGANIZATION

The operating organization responsible for possession and use of radiography sources and exposure devices has to obtain from the Regulatory Authority any authorizations necessary for their acquisition, storage and use, once the necessary prerequisites are met. The operating organization is responsible for carrying out industrial radiography in accordance with legislation and authorizations. Any condition laid down in the authorization has to be complied with. The management structure will vary with the size and complexity of the organization. However, it establishes clear lines of responsibility and accountability for the protection and safety of the sources throughout their operational lifetime within an organization, up to safe disposal.

The senior management of the operating organization needs to make a commitment to safety, to keeping doses as low as reasonably achievable (ALARA), and has to publicize this to all personnel. This will foster the appropriate safety culture within the operating organization. Good safety performance is a factor that must 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 performance of managers, supervisors and radiographers is judged.

The operating organization has to develop and implement a quality assurance programme, which defines the responsibilities on all levels and which details the requirements of the organization, personnel and equipment. The quality assurance programme is based on recognized national or international standards. Internal inspections or audits must be performed routinely and documented.

3.2.1. Appointment of qualified experts

The operating organization may appoint one or more suitably qualified persons as qualified experts (radiation protection advisers) to advise on matters relevant to radiation safety. The responsibility for compliance with the regulations is not delegated to the qualified expert and remains a responsibility of the operating organization. The appointment can be on a part time basis or as an outside consultant; a radiation protection adviser need not necessarily be an employee of the organization.

The qualified expert provides information and technical assistance on matters relating to radiation safety, including:

— equipment maintenance, calibration and repair;
— hazard assessments and emergency planning;
— commissioning;

— monitoring and dosimetry;
— internal inspections;
— emergency support;
— investigations of incidents, accidents and overexposures;
— training.

The qualifications of the qualified expert include :

(a) Theoretical training and practical experience to ensure the necessary knowledge of the properties of ionizing radiations used in industrial radiography.
(b) A knowledge of the hazards of the ionizing radiations present and the ways in which the hazards should be controlled and minimized.
(c) A general knowledge of the working practices in other organizations of the same type.
(d) A knowledge of all relevant regulatory provisions, codes of practice and international and national protection standards, guidance material and other information needed for the provision of advice in industrial radiography.

The operating organization has to provide the qualified expert with adequate information, facilities, equipment and support services as may be needed for the qualified expert to work effectively.

3.2.2. Appointment of radiation protection officers

The operating organization is to appoint at least one radiation protection officer (RPO) for overseeing the implementation of the radiation safety programme and to define the duties. These duties include:

— hazard assessment and drawing up emergency plans;
— restriction of exposure and maintenance of engineering controls and other equipment provided for such restriction;
— identification of controlled and supervised areas;
— control of access to controlled areas;
— dosimetry and monitoring;
— adequate monitoring of workplaces;
— drawing up and reviewing written administrative procedures that define the means of complying with regulatory or other requirements;
— drawing up and reviewing operational procedures to ensure that exposures to radiation are ALARA;
— investigation of abnormally high exposures and overexposures;

— supervision of radiography;
— implementation of the maintenance schedule of all safety related equipment;
— training;
— investigation of causes, consequences, remedial actions and accident prevention measures;
— deciding whether any special restrictions are required with respect to the exposure of declared pregnant female employees;
— prior examination of any plans for a new fixed facility or for modifications to an existing fixed facility from a radiation safety standpoint;
— maintaining required safety documents.

In cases where more than one RPO is assigned, the duties and responsibilities of each are well defined. Even in small organizations consisting of only a few employees, it is essential that someone with adequate knowledge and experience be assigned the role of RPO. The Regulatory Authority has to be notified of these appointments.

The RPO is to assist the operating organization in complying with the requirements of the authorization and regulations. Ideally, the RPO is a person whose responsibilities are separate from those of production, has experience as a radiographer and has a line management position enabling close supervision of radiographic work. However, this may not be possible in small operating organizations so that the owner may fulfil the role of the RPO. Even in this situation the necessary qualifications and experience are essential for the person who serves this role, as well as adequate time and resources to perform the duties.

The minimal requirements and qualities for appointment as an RPO are:

(a) theoretical training and practical experience as approved by the Regulatory Authority, to ensure the necessary knowledge of the properties of ionizing radiation and regulations used in industrial radiography;
(b) authority to command sufficient respect from the people doing the work to be able to exercise the necessary supervision of radiation protection and to stop unsafe practices.

The RPO may work in close association with qualified experts to ensure that all the required duties are fulfilled.

3.2.3. Appointment of qualified radiographers

The operating organization has to designate individuals who are authorized to operate radiography equipment. The radiographers' training, experience, attitude and competence as fostered and reinforced by the operating organization determine the degree of safety associated with daily radiography operation.

It may be required by the Regulatory Authority in some jurisdictions that all operators be at least 18 years of age, meet specified training and experience requirements and pass an examination set or approved by the Regulatory Authority or some other professional body. Whether such specified training and experience criteria are mandatory or not, the operating organization needs to ensure that all operators meet a minimum level in terms of knowledge of safety and radiation protection. Training includes both formal training and supervised hands on or practical training. Training topics include:

(a) Nature of ionizing radiation, radiobiological effects, and terminology and units of ionizing radiation.
(b) Dose and dose rates, including calculations using the inverse square law and decay laws, with an emphasis on the reduction of the high dose rate close to an unshielded source and characteristics of shielding materials. Time, distance and shielding as methods of protection.
(c) Measurement of radiation.
(d) Operating procedures to restrict radiation exposures to ALARA.
(e) Regulatory authority requirements.
(f) Safe storage and transportation requirements.
(g) Specific instruction on operation of each piece of equipment to be used (including exposure devices, personal dose monitoring radiation, survey meters and emergency equipment).
(h) Case histories of radiographic incidents and emergency response procedures (including practice drills).
(i) Testing and maintenance of equipment.

3.2.4. Personnel information, instruction and training

All other personnel such as assistant radiographers, drivers and storemen who are occupationally exposed have to receive information, instruction and training to the extent necessary to enable them to conduct their work in accordance with the requirements of the operating organization and the Regulatory Authority. Examples of the topics in which these personnel are trained may include:

(a) the nature of ionizing radiation;
(b) the health hazards from exposure to such radiations;
(c) the basic principles and methods of protection (e.g. time, distance and shielding);
(d) measurement of radiation fields and the units of measurement;
(e) the warning signs and signals and any actions to be taken;
(f) actions to be taken in emergencies.

Training needs to be reinforced regularly, updated when necessary and documented. A periodic review of training is undertaken to ensure its relevance and compliance with Regulatory Authority requirements. New personnel need to receive the required training before working with radioactive materials.

3.2.5. Personal monitoring

Workers (for example, radiographers, assistant radiographers, RPOs, service and maintenance personnel, emergency/accident personnel) who may receive significant occupational doses (as defined by the Regulatory Authority) have to wear appropriate personal dosimeters (e.g. film, thermoluminescent dosimeters (TLDs)), provided and processed by a laboratory or company that has been authorized by the Regulatory Authority. In addition, a direct reading dosimeter and an audible or alarming ratemeter have to be carried by a radiographer working with ionizing radiation. Such devices are not a substitute for radiation survey meters.

The procedures for the monitoring of workers, including the type of dosimeter required and the frequency of replacement, are to be chosen in consultation with the RPO or qualified expert, and as required by the Regulatory Authority.

The results of personal monitoring measurements are to be recorded and reported as required by the Regulatory Authority. If an overexposure occurs or is suspected, the dosimeters have to be processed immediately. These and all reported dosimeter overexposures and abnormal exposures have to be investigated by the operating organization.

3.2.6. Workplace monitoring

The monitoring instrument is the single most important item of radiation safety related equipment. As such, it will have the following characteristics:

(a) it will have a response appropriate for the type of radiation being measured;
(b) it will be in good working condition;
(c) it will be formally calibrated and tested within a specified period;
(d) it will be capable of measuring dose rates within the range of 2.5 $\mu Sv \cdot h^{-1}$ to 2 $mSv \cdot h^{-1}$;
(e) it will continue to indicate ‘full scale’ at dose rates up to 100 $mSv \cdot h^{-1}$; and
(f) it will have readily obtainable batteries and a built-in battery check feature.

In the choice of an instrument for field site operations, consideration should be given to durability in bad weather and poor conditions, reliability, portability and ease of use in low light or in the dark.

A sufficient number of portable X ray and gamma radiation monitors need to be provided. Surveys are to be undertaken at representative positions in controlled and supervised areas at intervals as advised by the RPO. Records of surveys have to be kept for a period of time prescribed by the Regulatory Authority. This monitoring confirms the delineation of controlled and supervised areas and immediately indicates any failure in the control of the radiation source.

3.2.7. Testing and maintenance of equipment

The operating organization is responsible for regularly testing the safety functions of equipment as required by setting up a formal programme of maintenance and testing.

The formal programme of maintenance and testing should include:

(a) For shielded enclosures, regular testing of safety interlock components and emergency stop devices for correct operation, according to the instructions of the manufacturers. These tests are carried out by appropriately qualified persons.
(b) Radiation monitoring equipment is calibrated and tested before first use, after repair and at intervals approved by the Regulatory Authority. The pre-use test includes a test of the instrument's overload performance to ensure that it operates correctly up to the maximum credible dose rate it may encounter.
(c) Periodic examination of all safety critical components of gamma exposure devices and ancillary equipment. Typically, this is performed at least once a year.
(d) Periodic leak tests of radiography sources are carried out in a manner and at a frequency recommended by the source supplier or manufacturer and in accordance with regulatory or other requirements.
(e) Periodic examination of safety critical components of X ray exposure devices and ancillary equipment. The user generally examines equipment yearly.
(f) Any other specific preventive maintenance and testing procedures as recommended by the manufacturer.

Test results are to be recorded, and problems brought to the attention of appropriate persons in the operating organization. More detailed procedures for checks can be found in the IAEA Practical Radiation Safety Manual on Gamma Radiography [4].

Leak tests

Leak tests of radiography sources are to be generally performed at a frequency as set by the Regulatory Authority. This frequency is based on activity, classification

according to ISO (International Organization for Standardization) Standards ISO 2919 [5, 6], and on whether they are of a special form as described in Safety Standards Series No. ST-1 [7] supplier information and operational history. Leak test frequencies range from six months to several years. Typically, Co-60 sources of higher than 370 GBq (10 Ci) are to be leak tested at 6 or 12 month intervals. Ir-192 sources are not normally leak tested as they are typically removed from use within a year, owing to their short half-life. Sources in storage are not normally leak tested unless they are to be used, moved or transferred, or have been in storage for more than ten years.

If the test results indicate less than 200 Bq for a source wipe or 20 Bq for a wipe on an equivalent surface, no action other than record keeping is required. Tests which reveal the presence of contamination on the test sample are considered to be evidence that the sealed source is leaking. In this event, the source should immediately be withdrawn from service, and appropriate action should be taken to prevent exposure of personnel and dispersal of radioactive material. The operating organization has to notify the Regulatory Authority immediately.

3.2.8. Operational instructions

Operational instructions are needed to operate equipment safely and need to be fully understood by the authorized personnel. It may be necessary to have these instructions in local language. The instructions should as a minimum include the following:

(a) A reminder of the nature of the hazard posed by industrial radiography and the safety features to control the hazard.
(b) A reference to the existence and location of written emergency procedures.
(c) A description of the safety organization, including the functions, duties and responsibilities of the RPO and workers.
(d) A description of routine operating instructions.
(e) A description of the required radiation surveys to be performed during radiographic work.
(f) A description and schedule of internal inspections and test procedures for ensuring that all safety systems, devices and components are functioning properly. Each safety item is to be designated, and the appropriate test, check and internal inspection applicable to it are to be specified.
(g) A description of proper use of personal radiation monitoring devices.
(h) Instructions covering actions to be taken in the event of equipment malfunction, such as failure to terminate X ray emissions, or leaking or stuck radiography sources.
(i) Procedures for proper movement, transport, storage and disposal of sources.

(j) Instructions for inventory control using records showing the location of each source and the worker responsible for it at all times.

The RPO has to establish investigational levels for unusual exposures, even if they are below the established dose limits. The radiographer is to notify the RPO of any exposures greater than 100 μSv/day and 2 mSv/month.

Decommissioning

The operating organization is to ensure that activity and volume of any radioactive waste for which it is responsible are kept to the minimum practicable, monitored and managed. The waste needs to be collected, handled, treated, conditioned, transported, stored and disposed of in accordance with the requirements of the Regulatory Authority and other applicable standards such as the IAEA's Radioactive Waste Safety (RADWASS) programme [8, 9].

The operating organization has to be aware of when the exposure container and sealed source have reached the end of their working life and when they are to be disposed of in a safe and proper manner in accordance with national regulations. These sources, as well as those which are no longer in use, may be transferred to the manufacturer by agreement, or to other authorized waste managers.

3.3. INDUSTRIAL RADIOGRAPHER/WORKER

Industrial radiographers have an important responsibility for ensuring the safe conduct of their work. Their safety and that of other workers in the immediate vicinity depends on their observance of a high standard of radiation safety at all times. The public and other persons who are in the immediate vicinity when radiography is in progress can be adversely affected if the work is not carried out to the required level of competence.

The radiographer needs to achieve a level of competence by study and training which is recognized and accepted by appropriate professional bodies, competent authorities, employers and potential clients. Formal training is to be supplemented by appropriate experience and the exchange of information, both theoretical and practical, with peers.

The radiographer is to undergo periodic refresher training in radiation safety. It is important for radiographers to keep up to date with the technology used in the field and to fully understand the correct use of the radiographic and ancillary equipment provided.

The radiographer has to maintain a professional attitude towards his or her work and the essential safety requirements. He or she needs to be alert and fully fit during

working hours. Adequate supervision is to be exercised over less qualified workers who may be called upon to assist.

Each radiographer has to receive any medical examinations as approved by the Regulatory Authority to confirm fitness for work with ionizing radiation.

The radiographer is to wear suitable dosimeters, as directed by the RPO, during working time, to measure the total exposure to radiation.

The radiographer should not expose him/herself or others to radiation unnecessarily to ensure that the dose he/she receives is ALARA. No work is to be undertaken which would place the radiographer at risk of receiving a dose greater than any relevant national dose limit except in emergency situations.

In the often difficult and adverse conditions of industrial sites, the radiographer also has to consider non-radiological hazards and to wear appropriate protective equipment. The radiographer is not to take risks that might jeopardize the integrity, safety or security of radiation equipment, particularly radioactive sources, or other radiation sensitive equipment.

All necessary care is to be taken to maintain radiographic and ancillary equipment in the condition necessary to operate safely. Equipment is not to be modified, abused or used for purposes for which it was not intended.

Equipment which is not in proper working condition is not to be used. The radiographer has to be vigilant in identifying apparent problems and to report any defects for repair.

The radiographer is to perform all appropriate surveys to assess radiation hazards. In particular, accidental exposures are prevented by using the radiation survey meter when approaching the exposure device and by surveying the exposure device following every radiographic exposure.

The radiographer has to be prepared to deal with reasonably foreseeable incidents with the necessary equipment. Unusual events, accidents and incidents are to be reported to the RPO.

The radiographer is to exercise appropriate care at all times and work in accordance with instructions and defined operating and safety procedures.

3.4. THE MANUFACTURERS AND SUPPLIERS

Devices for industrial gamma radiography are to be designed for the conditions likely to be encountered in use. All new equipment has to be manufactured and classified according to ISO 3999 [10], an equivalent standard, or the national requirement. Sealed sources are to be in compliance with the requirements of ISO 2919 [5]. If sources or exposure containers are to be transported, they are to comply with IAEA Safety Standards Series No. ST-1 [7].

3.4.1. Tests

Approval testing of all device prototypes is to be carried out in accordance with ISO 9000 [11] or an equivalent national standard by a body which is recognized by a national government as being qualified to make a full and impartial assessment.

If an exposure container is designed for use in more than one class and/or category, the prototype is to be subjected to the tests of each appropriate class and/or category.

With each device, the manufacturer has to provide a certificate of conformity of the device to identify the standards met. Test data may be requested from the manufacturer as specified by national requirements.

3.4.2. Instructions for use and maintenance

The operations manual provides instructions for:

(a) Assembling the exposure device and ancillary equipment for safe operation.
(b) Operating the exposure device with a warning of the risk of radiation exposure that may result from the failure to observe these instructions.
(c) Storing the exposure device in a suitable environment, with any necessary protective coverings.
(d) The scope and frequency of routine maintenance operations and checks on exposure devices and ancillary equipment, such as control cables, guide tubes and exposure heads.
(e) Remote control system maintenance.
(f) Procedures in the event of foreseeable accidents with an indication of their probable causes.
(g) Performing a gamma source exchange and preparing the decayed source for transportation and disposal.
(h) Checking projection and source guide tubes and the exposure head for internal cleanness, deformation, breakage or tear.
(i) Checking safety critical components of the exposure device for wear, breakage or deformation.
(j) Limitations on use, i.e. environmental conditions.

Documentation on source classification, special form and leak testing is to be provided by the manufacturer.

3.4.3. Quality assurance programme

A standard for the quality assurance programme is established according to the ISO 9000-1 [11], an equivalent standard, or a national standard for the design, manufacture, testing, inspection and documentation of all sources and devices.

The quality assurance programme provides assurance that the design satisfies all appropriate standards applicable to the sources and devices. Any subsequent discovery of problems which may compromise safety is to be brought to the attention of all previous purchasers of similar equipment.

A documented quality assurance manual needs to be established and maintained by each manufacturer of the sources and exposure devices for industrial radiography. This manual documents the implementation of all aspects of the quality assurance programme including organization; design control; procurement document control; instructions, procedures and drawings; document control; control of purchased material, equipment and services; identification and control of material, parts and components; control of special processes; internal inspection and test control; control of measuring and test equipment; corrective actions; handling, storage and shipping control; quality assurance records; and audits.

Radiography sources and gamma exposure devices to be transported need to meet the quality assurance programme specified in IAEA Safety Standards Series No. ST-1 [7] and/or relevant national requirements.

3.5. THE CLIENT

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

The client needs to provide the operating organization with sufficient lead time to plan and execute the work safely and to enable compliance with any advance notifications required by the Regulatory Authority.

The client is not to impose contractual conditions that would hinder the operating organization from performing safe radiography. In general, regulatory and safety requirements take precedence.

The client is to ensure that radiography is co-ordinated with other work on site to minimize the risk of radiation or other hazards to all workers on site, including the radiographer. A permit-to-work system helps to ensure effective communication and co-ordination of different jobs on site.

The client is responsible for providing a safe working environment for the radiographers, including secure scaffolding, adequate lighting and arrangements for working in vessels or trenches.

TABLE I. TYPICAL RADIONUCLIDES USED IN INDUSTRIAL RADIOGRAPHY

Radionuclide	Gamma energies (MeV)	Half-life	Optimum steel thickness of object material (mm)
Cobalt-60	High (1.17 and 1.33)	5.3 years	50–150
Caesium-137	High (0.662)	30 years	50–100
Iridium-192	Medium (0.2–1.4)	74 days	10–70
Selenium-75	Medium (0.12–0.97)	120 days	4–28
Ytterbium-169	Low (0.008–0.31)	32 days	2.5–15

If necessary and possible, the client provides a suitable location for the radiography company to safely and securely store radioactive materials.

4. TYPES OF EXPOSURE DEVICES

A wide range of exposure devices are commercially available to carry out industrial radiography. The range includes equipment for performing gamma and X ray radiography, and a summary of their general characteristics is provided. Neutron radiography, a specialized technique, is briefly mentioned.

4.1. GAMMA RADIOGRAPHY SOURCES AND CONTAINERS

The minimum requirements for gamma ray sources for industrial radiography are contained in ISO Standard 2919 [5] and generally satisfy the requirements for special form radioactive material [7]. Iridium-192 is ideal for radiography, but other radionuclides can be used, depending on the characteristics of the test object material (Table I).

The sealed source is to be stored in a safely shielded location within the specially designed exposure container. The sealed source is usually attached to a control cable, source holder or source assembly and has appropriate permanent markings. A definitive action by the radiographer is necessary to expose the source. The source is to be exposed only to the extent that is necessary to produce a satisfactory radiograph. After the radiographic exposure, the source is to be returned to its safe stored position. Dummy sources or photographs of the sources will help

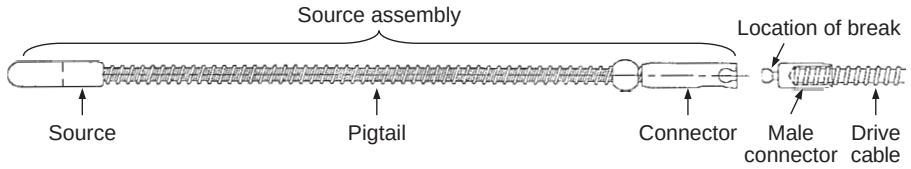

FIG. 1. A source assembly.

radiographers to recognize and identify the real ones in an emergency. A sketch of a source assembly is shown in Fig. 1.

The manufacturer sometimes provides a recommended working lifetime (RWL) for a source. These manufacturers recommend that work with a source stops when the age of the source reaches the RWL. The Regulatory Authority 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 appropriate facilities.

The sealed source has to be stored 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. The exposure container and ancillary equipment have to comply with the requirements of ISO 3999 [10], an equivalent

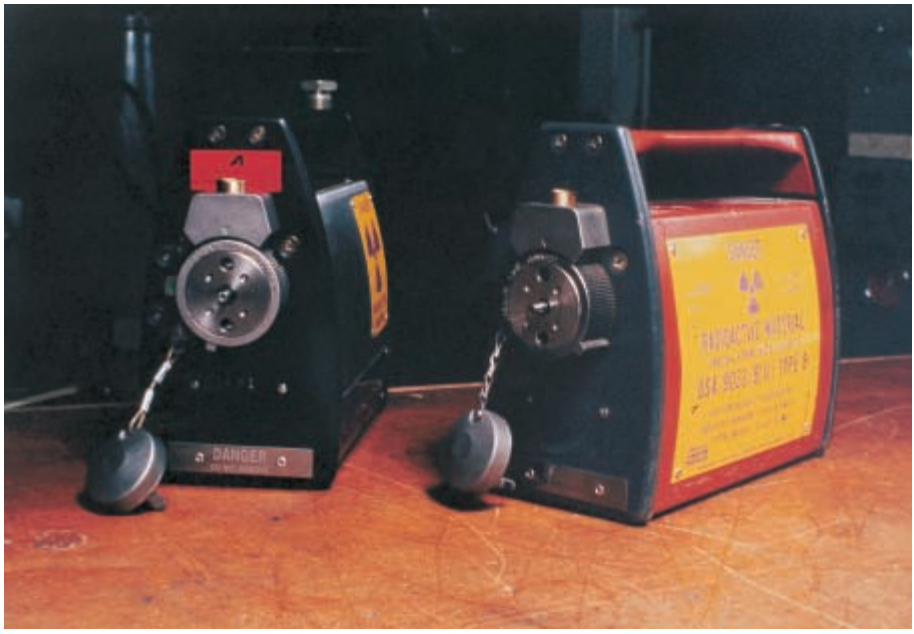

FIG. 2. Class P portable exposure device.

FIG. 3. Class M mobile exposure device.

standard or national requirements. The standard satisfied by the exposure container and the ancillary equipment is documented for review by the Regulatory Authority.

Containers are classified according to their mobility. Figures 2 and 3 show Class P and Class M, respectively, portable and mobile exposure devices:

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.

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

The three classes of exposure container generally operate by exposing the source in one of two ways, as depicted in Figs 4 to 6.

Category I: The source is not removed from the exposure container for an exposure. The source is stored at the centre of a block of shielding material. A portion of the shielding can be removed, or the shielding or source is moved to expose the source. The solid angle of the useful beam is not usually more than 60°. The container usually limits the beam dimensions, but additional collimation may be used to limit the beam further to the minimum size necessary for radiography. The movement is controlled either directly or by remote means.

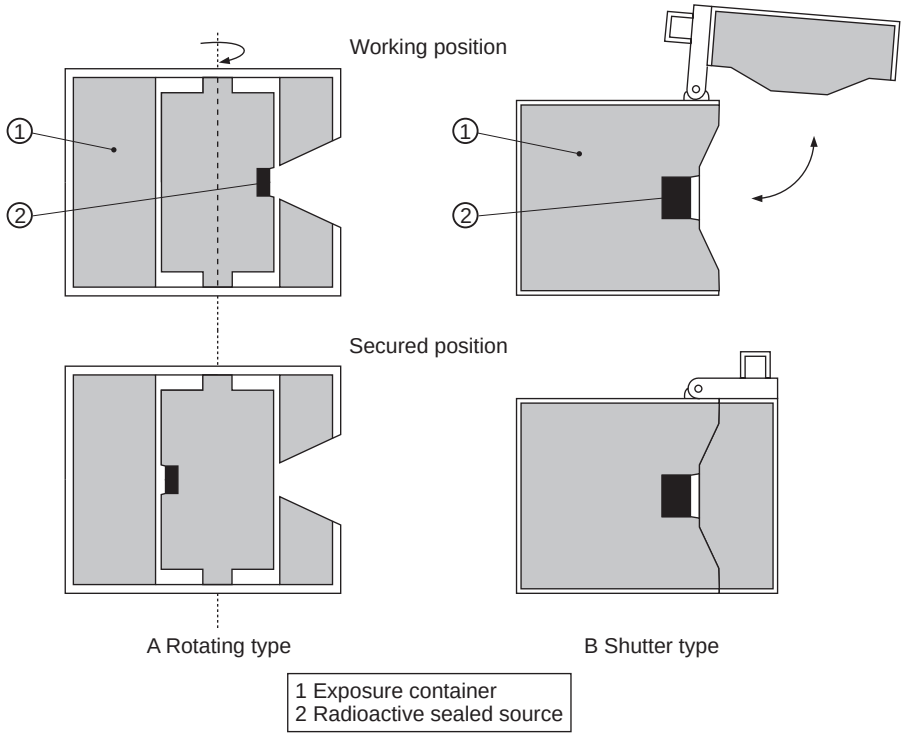

FIG. 4. Category I exposure device.

Category II: The source assembly is mechanically projected out of the container and travels along a guide tube projection sheath to the exposure head. The projection is hand or motor driven by the radiographer. The source assembly is usually moved by a cable. 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 Authorities will not authorize the use of such systems. Projection systems enable the radiographer to operate the system at a safe distance from the source. 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.

Some gamma exposure devices are designed for special applications, such as pipe crawler equipment and underwater radiography apparatus.

Gamma exposure devices are not to be used in conditions for which they were not designed. The effects of corrosion, moisture, mud, sand and other foreign matter are to be considered during design and manufacture of the container.

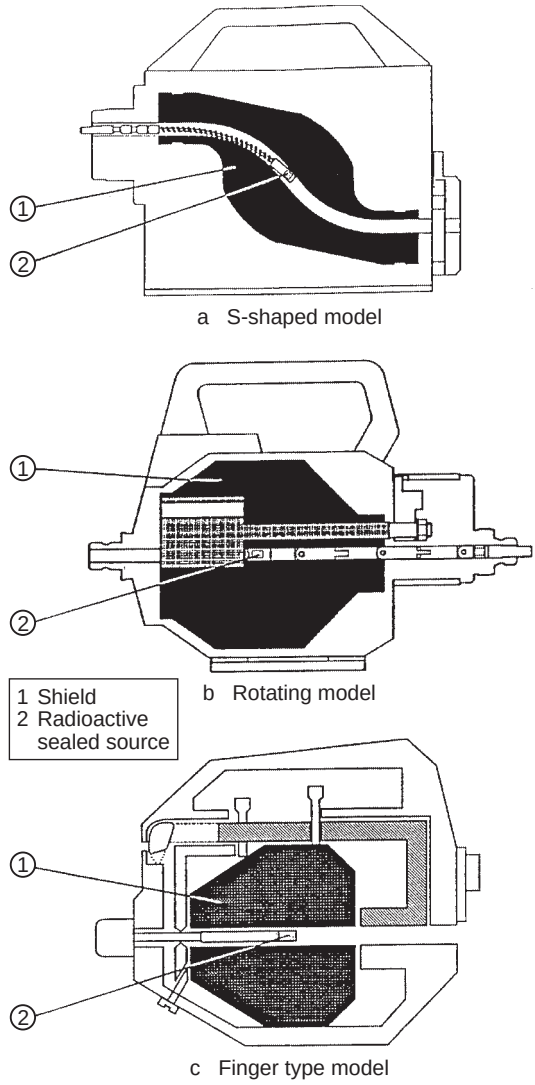

FIG. 5. Category II exposure container.

Approved standards in place will ensure the control of dose rates to acceptable levels close to the exposure container. For example, ISO 3999 [10] specifies the dose rate limits for the various classes of exposure containers as shown in Table II.

Exposure containers are often designed as transport packages and are tested and certified to Type B standards [7]. They will withstand severe impact forces, crushing forces, immersion in liquid and heat stress without release of radioactive contents or significant loss of shielding.

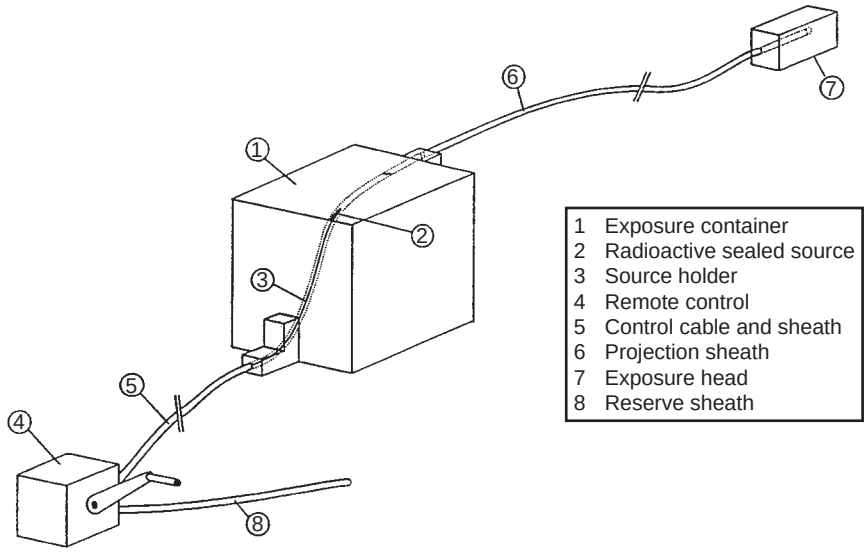

FIG. 6. Category II gamma radiography apparatus.

All exposure containers are to be fitted with an integral lock, which retains the key when the source is in the exposed position. If the lock is damaged it does not prevent the source assembly from returning from the exposed to the secure position.

TABLE II. MAXIMUM DOSE RATES ALLOWED PER CLASSES OF CONTAINER (ISO 3999)

Class	Maximum dose equivalent rate ($\mu Sv \cdot h^{1}$ (mrem$\cdot h^{-1}$))		
	On external surface of container	At 50 mm from external surface of container	At 1 mm from external surface of container
P	2000 (200)	500 (50)	20 (2)
M	2000 (200)	1000 (100)	50 (5)
F	2000 (200)	1000 (100)	100 (10)

Each exposure container or a metallic plate fixed to the container is to be permanently and indelibly marked by engraving, stamping or other means with approved details including:

(a) the basic ionizing radiation symbol complying with the International Organization for Standardization (ISO 361);
(b) the word RADIOACTIVE in letters not less than 10 mm in height;
(c) the maximum rating of the exposure container for the intended radionuclides in becquerels (Bq);
(d) ISO 3999 [10] or equivalent standard and edition which the exposure container and its accessories conform to;
(e) the exposure container manufacturer's name, the model number and serial number of the device;
(f) the class, category and total mass of the exposure container;
(g) the mass of depleted uranium shielding, if applicable, or the indication 'Contains depleted uranium.'

In addition, the exposure container displays a durable fireproof label or tag bearing information about the radioactive source contained in the exposure device, including:

(a) the chemical symbol and mass number of the radionuclide;
(b) the activity and date on which it was measured in Bq (or Ci);
(c) the identification number of the sealed source; and
(d) the identity of the source manufacturer.

Whenever a new source assembly is installed in an exposure container, the source identification tag has to be changed.

It is desirable to use modern exposure containers which incorporate safety devices and features designed to reduce the risk of human error or equipment malfunction. The current final draft of ISO 3999 [10] requires that Category II exposure containers incorporate features which automatically secure the source in the stored position after each exposure. It is then only possible to expose the source by deliberately releasing a mechanism on the exposure container. In addition, such exposure containers cannot be operated unless a secure attachment is made between the control cable and the source assembly, between the remote control cable and the exposure container and between the guide tube and the exposure container. Equipment manufactured to this standard is currently available.

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.

FIG. 7. Panoramic radiating tube assembly with conical anode.

When the radiography source and the exposure container have reached the end of their working lives or when use is discontinued, they have to be transferred or disposed of in a safe and proper way. Most exposure containers contain depleted uranium shielding which is radioactive and must be disposed of appropriately. The source and exposure container are generally returned to the manufacturer, upon prior agreement.

A source changer is a device used to transport new sources from the manufacturer to the operating organization. All source changes are to be performed in a controlled area by trained and authorized workers. The source changer is to be coupled to an exposure container, and the old source transferred from the exposure container to an empty channel in the source changer. Then the new source is transferred from source changer to exposure container. Upon prior agreement, the old source is returned to the manufacturer in the source changer.

4.2. X RAY RADIOGRAPHY EQUIPMENT

The general requirements for X ray machines for industrial radiography and fluoroscopy are laid down in various national standards and publications [12, 13]. Two types of portable X ray tube assemblies (also called tubeheads) are common for performing panoramic (radial beam) and directional exposures as illustrated in Figs 7 and 8. The tube assembly is connected by cable to the control panel, which provides

FIG. 8. Direct radiating portable X ray tube assembly.

the means for activation and operation of the X ray equipment, or for the preselection and indication of operating parameters. The dose to the radiographer is affected by the cable length, X ray tube parameters and the tube assembly. Where radiography cannot be carried out in a shielded enclosure, cable lengths typically are no less than 20 m for X ray generators up to 300 kV and longer for equipment with higher tube potentials. Cables are laid out as straight as possible to maximize the benefit of distance between radiographer and tube assembly.

Directional X ray tube assemblies are fitted with suitable collimators (also called cones and diaphragms) to reduce the useful beam to the minimum size necessary for the work and to minimize the radiation scattered from the irradiated object. Dose rates in the vicinity of the irradiated object are also reduced by the addition of suitable beam filtration.

Electrical safety contributes indirectly to radiation safety, since electrical faults in X ray equipment have resulted in serious accidents, some with radiological consequences. X ray equipment needs to conform to national and international electrical requirements [14–16]. All metallic items including casings, interconnecting cables, power supply unit (transformer/generator), X ray control equipment, tube assembly, warning signals, other safety devices and the irradiated object are bonded together and grounded (connected to earth). Advice on electrical matters, as well as inspection and testing, can be provided by a qualified expert.

X ray equipment has to comply with regulations pertaining to the standards of design, construction and functioning required by the relevant Regulatory Authority. Where no applicable regulations exist, the following safety features are the minimum requirements.

The control panel is outfitted with the following:

— A label which indicates that hazardous X rays are emitted when the equipment is operating, and a warning prohibiting unauthorized use. The international trefoil, ISO 361, and any other relevant warning symbol are displayed.

— A key switch to prevent unauthorized use. The key is removable only when the switch is in the ‘off’ or ‘standby’ position (no X rays can be generated) and the key positions are clearly marked.

— Separate labelled warning lights to indicate when the machine is energized and when X rays are being generated.

— A timer that controls the exposure duration, or an X ray ON/OFF 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.

The following features of the X ray assembly are necessary:

— Leakage radiation penetrates the wall of the X ray tube assembly to produce dose rates other than those in the main beam. 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 and are available for review by the Regulatory Authority. Typical maximum dose rate values of leakage radiation from commercial assemblies are up to 100 $\mu Sv \cdot h^{-1}$ at 1 m from the target.
— The X ray tube assembly has a support that maintains the tube position without tipping, slipping or vibrating during the operation of the machine.

4.3. ACCELERATORS

Accelerators can be used to generate high energy X rays (typically, 5 MeV) for radiographic examinations requiring highly penetrating radiation. If the object to be radiographed will fit into an enclosure, then the X rays can be generated by a large accelerator. This can be a linear accelerator housed in a shielded room adjacent to the shielded radiography enclosure. Radiographic examinations of large structures such as bridges are done on site, and accelerators for this type of work are smaller, usually cyclotrons. A mobile accelerator may be mounted on a large vehicle (e.g. truck) with the accelerator head being mounted on a gantry to enable positioning of the radiation beam. A portable accelerator (Fig. 9) can be transported in a small vehicle (e.g. car) and carried into position by the radiographers. The portable accelerator weighs approximately 100 kg, with the ancillary equipment (e.g. controller, control panel, warning signals) being of similar weight.

4.4. UNDERWATER RADIOGRAPHY EQUIPMENT

For radiography under water, exposure containers are to be provided with additional safety features. The necessary features include:

(a) A depth rating stating the maximum depth at which the container may be safely used.
(b) 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.
(c) A windout (Category II containers), exposure or shutter (Category I containers) control mechanism which can be operated outside the controlled area.

FIG. 9. Portable X ray betatron.

4.5. PIPE CRAWLER EQUIPMENT

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 of 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 (^{137}Cs) sealed source mounted in a hand-held device and collimated. Radiation from the control source is received by a detector on the crawler. 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 abruptly 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.

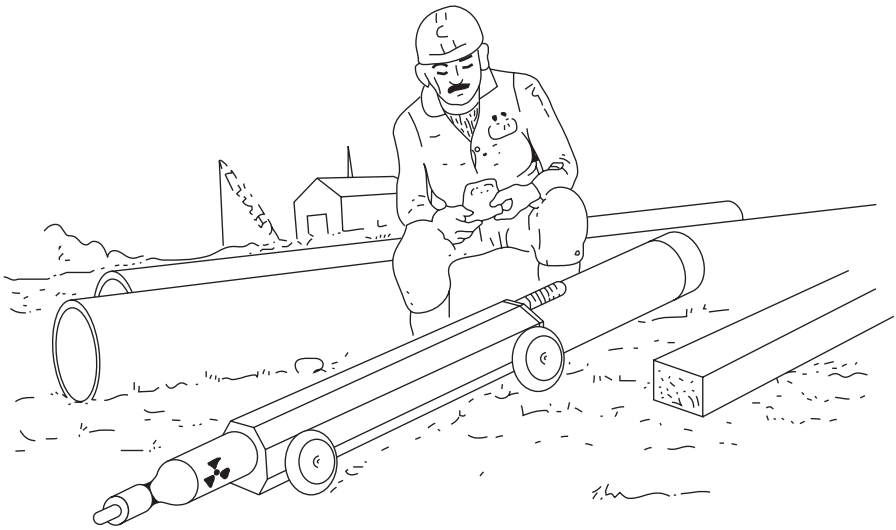

FIG. 10. Gamma pipeline crawler.

The pipe crawler and the control source are to be prepared and transported in accordance with the requirements of IAEA Safety Standards Series No. ST-1 [7]. A gamma pipeliner crawler is shown in Fig. 10, and Fig. 11 shows the general construction.

4.6. REAL TIME RADIOGRAPHY

A variety of exposure devices are in use or under development for special applications. In order to keep pace with faster welding techniques and commercial

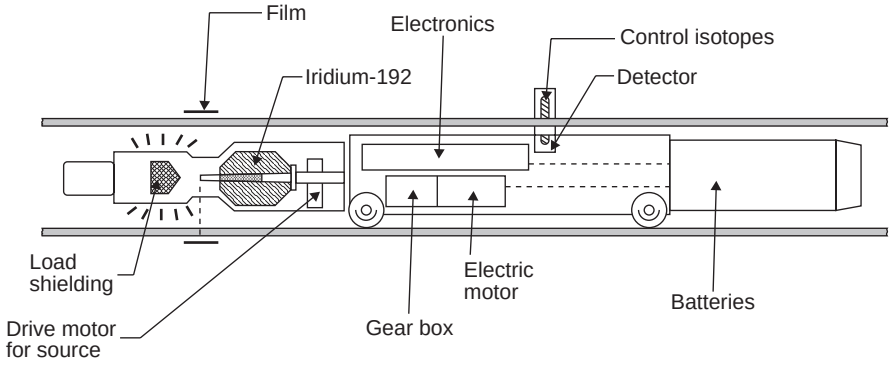

FIG. 11. Cross-section of pipeline crawler.

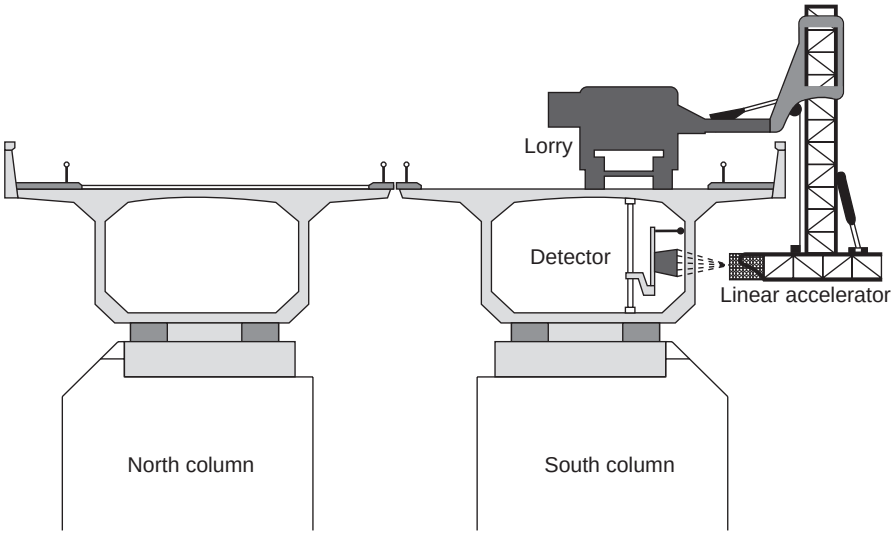

FIG. 12. Real time radiography (radioscopy) of a bridge.

production needs, real time radiography, which is also called fluoroscopic imaging, uses digitally processed images displayed on a high resolution monitor instead of on conventional X ray film. The X ray tubehead or exposure container is mounted diametrically opposite a radiation detector. The objects to be radiographed are brought in front of the exposed source by using a conveyor system, or the source and the detector are rotated around the object by a computer controlled motor. Both methods produce a digitized image on a screen. The person interpreting the radiographic image views the meter on several monitors and must decide to accept or reject each image before the system proceeds to the next frame. A real time system allows radiography of large cast housings, as shown in Fig. 12.

4.7. NEUTRON RADIOGRAPHY

Although still in its infancy, neutron radiography is being steadily developed. The range of applications includes the use of steady state and pulsed beams of neutrons over a range of energies: subthermal, thermal, epithermal and fast. In contrast to X and gamma rays, neutrons more easily penetrate heavy metals such as steel, lead and uranium but neutrons are absorbed or scattered in low density hydrogenous substances and certain materials such as hydrides, boron, plastics, cadmium and gadolinium. Neutron sources include both radioisotopes and accelerators.

5. DESIGN AND USE OF SHIELDED ENCLOSURES (FIXED FACILITIES)

5.1. ENCLOSURE DESIGN AND USE

Experience shows that, in general, industrial radiography is most safely carried out in a shielded enclosure. The use of an enclosure offers the benefit of allowing other work in the vicinity to continue without interruption and allowing radiography to be carried out as required. There is little doubt that, where it is reasonably practicable to carry out radiography in a shielded enclosure, the radiation doses resulting from the work will be kept ALARA. Properly designed and operated shielded enclosures can help to keep the radiation exposure of workers to 5 mSv (or less) per year.

A shielded enclosure is an enclosed space engineered to provide adequate shielding from ionizing radiation to persons in the vicinity. The general design principles are similar for all enclosures, although different characteristics are incorporated, depending on whether the enclosure is to be suitable for X ray, accelerator or gamma radiation equipment.

A shielded enclosure, which is designed for specific work and operated within its design limitations, can shield ionizing radiations in such a way that no controlled area is created outside the enclosure. A controlled area within the shielded enclosure exists during performance of radiography and may also exist owing to the storage of radiography sources alone.

A supervised area may need to be designated outside the shielded enclosure where the conditions do not constitute a controlled area but where occupational exposure conditions need to be kept under review. Specific protection measures and safety provisions are not normally needed for a supervised area.

In establishing supervised areas associated with any shielded enclosure, the operating organization, taking into account the nature and extent of radiation hazards, has to

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

As applicable, the siting, location, design, construction, assembly, commissioning, operation, maintenance and decommissioning of any shielded enclosure are to be based on sound engineering principles and have to

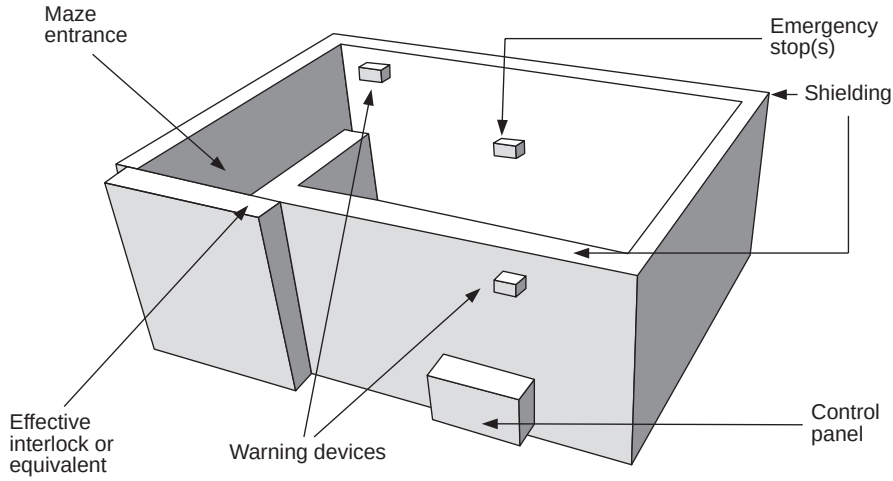

FIG. 13. Shielded enclosure.

(a) take account of regulatory requirements, approved codes and standards;
(b) ensure protection to restrict exposures; and
(c) be designed to prevent accidents.

Designs of shielded enclosures require guidance in terms of anticipated doses, dose rates and exposure times. Designs are to be based on the ALARA principle (Section 2) and on any additional dose constraints that may have been specified by the Regulatory Authority. Design considerations for these installations include: (a) shielding considerations, (b) personnel access door interlocks, (c) fixed radiation monitors, (d) warning signs and symbols, and (e) emergency stops. An outline sketch of a shielded enclosure is shown in Fig. 13.

5.2. SHIELDING DESIGN FOR A SHIELDED ENCLOSURE

It is important to plan the design of the shielded enclosure for immediate and foreseeable future needs before commencing construction. Annotated drawings or sketches are prepared of the installation and its surroundings, including dimensions of each enclosed area, thickness, density and type of shielding material on all sides, including above and below the exposure area. Entrances are identified, and distances to potentially occupied areas adjacent to, above and below the exposure area are indicated. 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 in practice.

Direct radiation exposure and scatter from the operation of shielded enclosures must be limited by appropriate shielding. A competent estimate of the thickness of the shield needed requires transmission graphs which are published for different radionuclides [17] and X ray machines [18]. A simplified method of estimating shielding thickness is possible [19]. The design principles are similar for all shielded enclosures although different shielding characteristics are incorporated, depending on whether the shielded enclosure will be used for X rays or gamma radiation. Also, the shielding design should consider both the primary and the scattered radiation and the prevention of air scattering (skyshine) in facilities with minimal or no roof shielding. The amount of shielding is to be calculated with reference to the dose rate, use factor and occupancy factor.

Some penetrations of the shield will be necessary for personnel entry and exit, cranes to place and remove heavy objects to be radiographed, pipework, control cables, ventilation and other ducting. Radiation which either penetrates or scatters around weaknesses in the shielding can cause problems. Such weaknesses might occur after a period of wear, shielding damage, movement of shielding or building settlement. Various design techniques can be used to prevent or minimize these weaknesses [17, 18].

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 Authority or a qualified expert recognized by the Regulatory Authority to perform this function.

Shielded enclosures are to be used within the design constraints; changes in radionuclide type, source activity, radiation energy and intensity may require a change in the shielding provided. Documentation has to be kept, showing the results of calculations, radiation level measurements and maximum expected radiation levels inside the shielded enclosure and in all areas adjacent to it.

For shielded enclosures:

(a) appropriate instructions are provided at access points and other appropriate locations inside and outside the controlled areas;
(b) occupational radiation protection and safety measures are established, including local operating instructions and procedures that are appropriate for the controlled areas;
(c) access to shielded enclosures is restricted by administrative procedures, such as the use of permit-to-work systems; access doors are locked or interlocked for gamma radiography and interlocked for X ray radiography; the degree of restriction required is commensurate with the magnitude and likelihood of the exposures that would be expected.

5.3. CONTROL OF EXPOSURE IN SHIELDED ENCLOSURES

A wide range of radionuclides, source activities and X ray devices are used in shielded enclosures. Type P, M and F exposure containers are used as appropriate, containing one or more radiographic sources. Sources are kept secure to prevent unauthorized use, unauthorized removal or theft, or damage to the sources. If the radiographic sources are stored in the shielded enclosures, it may be necessary to designate these shielded enclosures as permanently controlled areas, even while no radiography is being carried out.

Shielded enclosures are to be fitted with suitable safeguards to ensure that people cannot gain unauthorized access to the radiation room while the exposure device is in the exposed position or is energized. Access control relies heavily on the use of interlocked systems. Suitable interlocks have to 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. Redundancy, diversity and independence of interlocks provide additional levels of safety. The interlock either prevents a person from entering during an exposure, immediately interrupts the electrical power to X ray machines or automatically shields radiographic sources. Subsequent closing of the interlock must not automatically re-energize the X ray machines or re-expose the radiography sources. Automatic exposure devices do not operate if the interlock is open.

For shielded enclosures for gamma radiography, a radiation monitoring system with built-in redundancy is to be installed. The radiation monitor is integrated with the door interlocks to prevent entry when the radiation monitor detects radiation in excess of a pre-set level. The same installed radiation monitor also triggers visible and audible alarm signals. Such a system does not obviate the need to use a portable survey meter when entering a shielded enclosure.

Emergency stop buttons or pull-cords are to be installed to enable any person within the shielded enclosure to quickly terminate or prevent the radiation exposure. These are located so that they can be reached without passing through the primary radiation beam and are labelled with clear instructions on their use. The emergency control system is to be designed to allow people then to leave the shielded enclosure or to summon assistance. The radiographer ought to be able to terminate the exposure immediately in an emergency.

Clearly visible signs bearing the radiation symbol (international trefoil) and warnings as required by the Regulatory Authority are to be posted at all doors to the shielded enclosure. Warning signs are made from materials that are durable under the prevailing environmental conditions and are replaced as necessary.

Visible warning signals have to be prominent and positioned in suitable locations. Audible warning signals have to be distinct and loud enough to gain the immediate attention of people in the area. The warning signals are to be

distinguishable and designed so as not to be confused with any other signals in use in the area. The meanings of the signals are to be explained in posted notices.

The following illuminated or colour coded controls are to be used:

Condition	*Colour*
Emergency (stop buttons or lights)	Red
Radiation on (no access)	Red and international trefoil
Warning (stand-by)	Amber and international trefoil
Radiation off (safe access)	Green
Information	Blue

The exposure control system for exposing a radioactive source or energizing an X ray machine is to be located outside the shielded enclosure.

5.4. OPERATING PROCEDURES FOR SHIELDED ENCLOSURES

Only authorized workers who have received the appropriate training are to operate shielded enclosures.

If the shielded enclosure is designated as a controlled area, it is appropriate for the authorized workers to have had medical examinations and to wear personal dosimeters (as specified by the Regulatory Authority). These dosimeters include film or thermoluminescent dosimeters, personal direct reading dosimeters and alarming dosimeters. 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 specifications. Written operating procedures have to be readily available as appropriate or required. Any changes to exposure devices or their use not considered in the design of the shielded enclosure may result in excessive dose rates outside the shielded enclosure. In practice, this means that different equipment or modified work procedures are not to be used without careful safety consideration and authorization.

A suitable portable survey meter has to be kept available to measure accessible dose rates outside the enclosure. The measurements are to be made at positions above ground level at a distance from the shielded enclosure and, in particular, when the radiation beam is operated at the limits of the shielded enclosure's design parameters.

Whenever the radiographer enters the shielded enclosure, he or she has to carry a portable survey meter. Before using the instrument, a check against a test source is performed to ensure that the instrument is working. This procedure is necessary and additional to any radiation measurements made by an installed monitoring system.

If it is desirable to use the shielded enclosure for purposes not originally covered or intended under the design specification in order to keep doses ALARA,

such as keeping the door open or using a gamma exposure device in an X ray radiography shielded enclosure, then site radiography procedures are to be followed. This includes ensuring that the dose rate at the control point is less than 2 $mSv \cdot h^{-1}$, and barriers and notices are set up to mark any controlled areas near the door or elsewhere.

Before the radiation source is exposed or energized, the shielded enclosure is to be checked by the radiographer to confirm that no person is inside. Exposures are to be initiated by the radiographer only when the door is closed, all essential shielding is in place, safety devices are in operation and warning signals are given.

6. SITE RADIOGRAPHY PROCEDURES

Most radiography is performed on-site and is influenced by a number of site specific conditions. Planning for safe operation includes consideration of the location, proximity of members of the general public, weather conditions, time of day, and work at height, in confined spaces or under difficult conditions. Owing to these conditions, site radiography needs to be performed with more than one radiographer. A typical site radiography set-up is shown in Fig. 14.

6.1. BOUNDARY OF CONTROLLED AREA

Site radiography needs to be done in an area where specific protection measures and safety provisions are in place, i.e. in an area designated as a controlled area. The boundary of the controlled area is to be set at a dose rate contour which is appropriate under the prevailing circumstances and specific exposure times and is authorized by the Regulatory Authority. This dose rate contour has to be set at a value ensuring that outside the controlled area the annual dose limits for the public are not exceeded, account being taken of nature and frequency of site radiography at a specific site use as well as occupancy factors where allowed. The boundary dose rates when collimators are used are typically in the range of 7.5 to 20 $\mu Sv \cdot h^{-1}$. The boundary dose rates are typically in the range of 50 $\mu Sv \cdot h^{-1}$ when it is not possible to use a collimator. The transient dose rates during radiography source windout operations will exceed these values. However, transient dose rates usually do not present a radiation protection problem as they occur only briefly.

The boundary of the controlled area has to 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. A typical set-up is illustrated in Fig. 14.

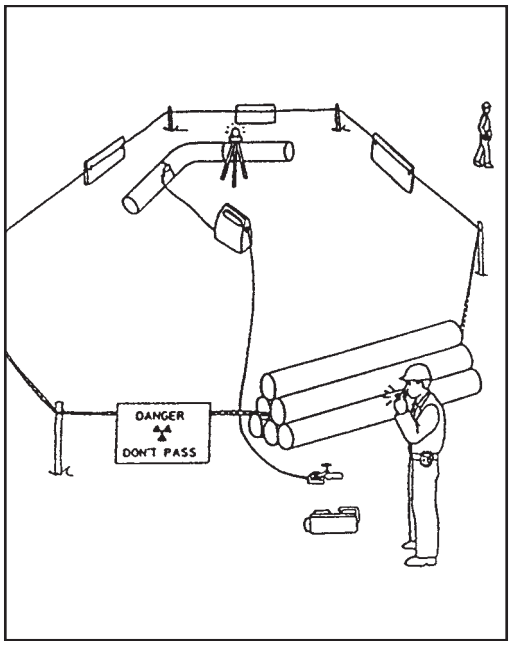

FIG. 14. Typical site radiography set-up.

6.1.1. Warning notices

Notices are displayed at the controlled area boundary at suitable positions. The notices bear the international radiation trefoil symbol, warnings and appropriate instructions in the local language.

6.1.2. Warning signals

In all cases adequate warning is to be given. Visible or audible signals or both are used where a radiographic source is exposed or an X ray machine is energized and surveillance is compromised. The use of visible and audible signals will help to reduce the likelihood of accidental exposures to radiation.

6.1.3. Patrolling and monitoring the boundary

Before the start of radiographic work, the area is to be cleared of all people except for authorized personnel.

The boundary should be clearly visible and well lit and continuously patrolled to ensure that unauthorized people do not enter the controlled area. If the boundary is

large, or if it cannot be seen from one position or not secured by physical means, more than one person will need to patrol the area.

The dose rates at representative points at the boundary are to be checked during radiography, particularly when the position of the radiography within the area or the direction of the radiation beam is changed.

6.2. SHIELDING

Shielding reduces both the size of the controlled area and the radiation doses received by radiographers. Shielding in the form of collimators is designed so that the radiation beam is primarily in the direction necessary for radiography. Collimators are made from depleted uranium (DU), tungsten or lead and give shape to the beam; beam shapes range from conical to panoramic-annular. Collimators are supplemented with other forms of additional local shielding such as lead shot, sheets and bricks.

Whenever it is possible to take advantage of existing shielding, such as walls, vehicles or shielded enclosures or similar structures to reduce radiation dose levels, radiography personnel need to arrange the disposition of the equipment and parts within the shielding afforded. Site radiography conditions are still applicable.

6.3. ADMINISTRATIVE ARRANGEMENTS

As the possible use of engineering means to restrict exposure during site radiography is limited, proper management controls, operating procedures and training are very important.

Unauthorized entry into the controlled area is not allowed when the radiation source is exposed. If possible the control point for initiation and termination of the radiation is outside the controlled area boundary. However, the radiographer may have to enter the controlled area to initiate the exposure, leave the area (or move to a shielded location, for example, where the dose rate is less than 2 $mSv \cdot h^{-1}$ and the exposure time is short) during the exposure and enter again to terminate the exposure.

Effective means of communication between the radiographic workers are to be used in order to avoid unintended exposures. Such a situation can occur when the radiographer operates the device and the radiographer changes films. In addition, effective communication reduces the need for retaking exposures, thereby keeping doses ALARA.

Exposure devices on site have to be secured against unauthorized removal or theft when not under direct surveillance. The devices are to be stored in a locked area for overnight or temporary storage, as for example during work breaks.

6.4. MONITORING

6.4.1. Personal dosimeters

Personal dosimeters such as thermoluminescent or film dosimeters and direct reading dosimeters are to be worn when radiographers are working with ionizing radiation. A personal dosimeter is worn only by the radiographer to whom it is issued, and it is securely stored in a non-radiation environment when not being worn. Personal dosimeters are to be regularly assessed for the radiation to which they have been exposed, as required by the Regulatory Authority. Direct reading dosimeters have to be periodically assessed by the radiographers to monitor doses received during radiography.

6.4.2. Portable survey meters

For site radiography operations, at least one portable survey meter has to be available for each working group. Before beginning the radiography, the meter is to be tested against a check source or by placing the meter's detector close to the exposure container to obtain a reference reading which can be referred to during radiography operations. This ascertains the reliability of the instrument and confirms that the radiographic source is in the secured position. Figure 15 shows the use of an instrument to survey the exposure device.

FIG. 15. Use of instrument to survey an exposure device.

During radiography, the primary survey objective is to determine that the radiographic source has returned to the shielded position or that the X ray emission has ceased for each radiographic exposure. Exposure devices have to 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 control having failed.

6.4.3. Personal alarm monitors

Radiographers need to use personal alarm monitors during the whole period they may be exposed to ionizing radiation. The alarm provides a recognizable signal at a suitable dose rate that may be prescribed by the Regulatory Authority. The signal is to be audible, visible or vibratory, and recognizable in the working environment. These alarms are used in addition to portable survey meters.

6.5. ADDITIONAL PRECAUTIONS FOR GAMMA RADIOGRAPHY

The radionuclide and the activity of the radiographic source are selected such that the dose for all workers is kept ALARA, consistent with obtaining adequate diagnostic information. It is possible to do most radiographic work by using iridium-192 with an activity of up to 1850 GBq (50 Ci). Advanced techniques are available, such as image intensifying screens or fast film and screen combinations, to keep doses ALARA.

Procedures need to be rehearsed, and only equipment that is specifically manufactured for gamma radiography is to be used. The radiographer needs to 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.

Radiography is 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;
— 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.

Before leaving the site, the radiographer carries out a visual examination to ensure that equipment has not been damaged. The exposure container is made ready for transport by locking the device and putting protective coverings in place. The exposure container and the ancillary equipment are physically secured in the vehicle to avoid damage during transport.

The following checks are made before use, as described in the operating procedures:

(a) Check the exposure container and exposed ends of cables for damage, wear or dirt. A wear gauge supplied by the manufacturer can be used;
(b) Check screws and nuts for tightness and screw threads and springs for damage;
(c) Confirm that the source locking mechanism works properly;
(d) Examine the end of the pigtail for wear, damage and proper connection to thecontrol cable; a wear gauge provided by the manufacturer can be used for this purpose;
(e) Check connections between the exposure container and cables for secure connection;
(f) Inspect all cables and guide tubes for cuts, breaks, kinks and broken fittings;
(g) Check the warning label and source tag details for legibility;
(h) Measure radiation levels close to the exposure container's surface for compliance with IAEA Safety Standards Series No. ST-1 [7] and to confirm that the source is shielded.

If any discrepancy is noted, the equipment is not to be used until a replacement is provided or a repair is made.

6.6. ADDITIONAL PRECAUTIONS FOR X RADIOGRAPHY INCLUDING USE OF ACCELERATORS

The procedures discussed in this section are applicable to the use of all X ray exposure devices 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, single wall versus double wall) is selected with regard to good image quality and reduction of the dose for all involved.

The following checks are made before use, as described in the operating procedures:

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

If any discrepancy is noted, the equipment is not used until a replacement is provided or a repair is made.

Accelerators generate very high energy X rays which increase the potential for overexposures of radiographers. Therefore, higher levels of radiation protection are required on site. The dose rate in the main beam of an accelerator is high and can range from 4 $Gy \cdot min^{-1}$ (240 $Gy \cdot h^{-1}$) from a mobile accelerator to 50 $mGy \cdot min^{-1}$ (3 $Gy \cdot h^{-1}$) from a portable accelerator. This means that the dose rate around the apparatus is much higher than during conventional X ray radiography, and so more comprehensive control measures are needed to restrict the exposure of people to ionizing radiation. In addition, appropriate portable survey meters are used that respond accurately to the pulsed nature of the radiation field (the radiation pulse duration and the pulse repetition frequency). Portable survey meters used for conventional gamma and X ray radiography may not be suitable for use with accelerators.

6.7. ADDITIONAL PRECAUTIONS FOR UNDERWATER RADIOGRAPHY

Underwater gamma radiography is a specialized technique that requires additional considerations:

(a) Appropriate training of divers is necessary.
(b) Before being taken into the water, the control mechanism and guide tube are to be connected to the exposure container, the connections need to be confirmed to be secure, and the source assembly has to be in the secured position.
(c) A short line with a buoy and an emergency location device (for example, a strobe light) are to be securely attached to the exposure device. This will aid recovery from the water if the exposure container is dropped.
(d) All equipment, such as survey meters to be used underwater, needs to be specifically suited to the purpose.

6.8. ADDITIONAL PRECAUTIONS FOR PIPELINE CRAWLERS

General radiation safety requirements for X ray and gamma exposure devices also apply to pipeline crawlers. With pipeline crawlers, the useful beam is restricted so that its width is no greater than is necessary for the radiograph. When in use, pipeline crawlers are not visible from outside the pipe; it is thus essential that suitable warning signals are given.

The warning signals of X ray pipeline crawlers have to operate automatically. It is desirable that gamma pipeline crawlers also operate in this way, where practicable, because unintended movement of the control source may inadvertently initiate an unplanned exposure. Warning signals have to be capable of alerting people in the vicinity of the pipeline crawler under the prevailing environmental conditions. Signals that operate automatically are to be linked with the operation of the pipeline crawler. Audible signals are attenuated by the pipe wall and need to be loud enough to locate the pipeline crawler accurately within the pipe. Klaxons and sirens can be used, provided that they can be heard in a noisy environment.

Possible supplementary signals outside the pipe include:

(a) a visual signal to supplement the audible signal in noisy environments;
(b) a radiation activated warning device that will indicate the position of the crawler equipment along the pipe.

Also, a portable survey meter is used to determine that the X ray emission has ceased or that the source has returned to the shielded position after each exposure. Personal alarm monitors worn by the radiographers also indicate whether the pipeline crawler equipment is emitting radiation nearby inside the pipe.

If a pipeline crawler breaks down, it may be necessary for a radiographer to enter the pipeline to retrieve it. Before entering, a check is to be made by the radiographer to ensure that the pipeline crawler is not emitting radiation. As a pipeline potentially contains welding fumes and toxic gases (e.g. from the pipeline crawler's internal combustion engine), checks are to be made to confirm that the atmosphere is safe before entry into the pipeline. Respiratory protective equipment may be necessary.

The radiographic source (if any) and the control source are to be housed in shielded containers and, together with the 'tell-tale' source, should not produce dose rates in excess of 100 $\mu Sv \cdot h^{-1}$ on the accessible surface of the pipeline, except during exposure. If the pipeline crawler is kept in the pipeline between radiographic exposures, a supervised or controlled area is set up around the pipe, as necessary. The control sequence is to be designed so that unintended exposures are prevented.

7. STORAGE, MOVEMENT AND TRANSPORT OF RADIOGRAPHIC SOURCES AND EXPOSURE DEVICES

7.1. STORAGE OF SOURCES

Storage facilities are designed to restrict exposure, keep radiographic sources, exposure containers and control sources secure against theft or damage, and prevent any unauthorized persons from carrying out any actions which would be dangerous to themselves or the public. Clear warning notices are to be displayed at the storage facilities.

A suitable storage facility for radiographic sources, exposure containers, control sources and ancillary equipment is one that provides protection from the prevailing environmental conditions. Resistance to fire is considered in constructing the storage facility in order to minimize loss of shielding and containment. The storage facility is to be located at a remote distance from corrosive and explosive hazards.

If the outside of the storage facility is accessible to the public, shielding is provided to reduce the dose rate in this area to less than 2.5 $\mu Sv \cdot h^{-1}$, or as authorized by the Regulatory Authority.

The door is to be kept locked, and the keys for the storage facility and exposure device controls are to be held only by authorized personnel.

Physical inventory checks are to be made periodically to confirm the location of radiographic sources, exposure containers and control sources.

7.2. MOVEMENT AND TRANSPORT OF SOURCES

When gamma exposure devices and sources are to be moved around a work site, they are not to be removed from the storage facility until they are ready to be used. The sources are to be moved only in appropriate containers such as transport packages which are locked correctly and the keys of which are removed.

A vehicle or trolley is best used to move the containers. Under these circumstances, the containers are secured to the vehicle or trolley, and are kept under surveillance for the duration of the movement on the work site.

The requirements for transportation of radioactive materials are published in the IAEA Safety Standards Series No. ST-1 [7] and other publications relating to specific modes of transportation from organizations such as they International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO). The main requirements spelled out in Ref. [7] are:

(a) All transport of radioactive sources should comply with the containment, labelling and documentation requirements and any existing national legislation.
(b) Provisions should be established to ensure compliance through the appointment of a Regulatory Authority for transport of radioactive materials. The Regulatory Authority sets up and executes a programme for monitoring the design, manufacturing, testing, inspection and maintenance quality assurance of packages.
(c) Industrial radiographic exposure containers should satisfy the requirements of Type A or Type B packages for transport. A summary of the requirements for these types of packages is included in Schedules 9 and 10 of IAEA Safety Series No. 80 [20].

Operating organizations are often the consignors (shippers) of exposure devices to and from temporary work sites, and therefore the responsibilities laid down for consignors in Ref. [7] are also applicable. They ensure that all packages are properly prepared for transport, including the securing of all required plugs, caps and locks before transport. All conditions of any applicable authorization for the package must be met.

Gamma exposure devices are frequently transported by road by the operating organizations. Drivers and vehicles must comply with the applicable requirements of national and international roads. These requirements prescribe the necessary safety equipment on vehicles, placarding, transport documentation and training of drivers.

In the event of a transport accident, the vehicle driver, local emergency services or any other person discovering the accident will contact the package consignor and/or the consignee who are identified on the transport documentation. Both organizations are to be fully aware of the emergency plans and provide or call for practical advice and assistance. IAEA Safety Series No. 87 [21] gives guidance and recommendations for dealing with transport accidents and is useful for the preparation of the transport emergency plan.

8. EMERGENCY RESPONSE PLANNING

Accidents have occurred in industrial radiography resulting in workers and members of the public being exposed to radiation and other health and safety hazards. Typical situations which have led to a radiological hazard include loss of control of the source or exposure device, damage to the source or exposure device, and direct contact with the source.

8.1. EMERGENCIES RESULTING IN EXPOSURES

Experience and analysis of the kind described in Ref. [3] have shown that the most likely events involving gamma exposure devices with the greatest potential for significant radiation exposure to workers and the general public concern:

(a) failure to retract the source and failure to perform an adequate radiation monitoring survey;
(b) a source stuck in the guide tube, collimator or near the entrance to the exposure container;
(c) source disconnection from the camera cable;
(d) an exposure device stuck in the exposed position, such as a shutter remaining open;
(e) theft of the exposure device or source assembly;
(f) malfunction or deliberate defeat of the safety control system;
(g) contamination due to leaking or damaged sources.

The most serious exposures occur when a worker remains next to, or physically handles, the unshielded source assembly, when the source assembly is mishandled or when it is in the possession of members of the general public. The dose rates are high enough to cause localized overexposure in a matter of seconds or minutes and can result in severe injury and even death.

The most likely events involving X ray exposure devices with potential for significant exposure to workers are:

(a) an automatic exposure timer fails to terminate an exposure resulting in the tube assembly remaining energized;
(b) the tube assembly is energized unintentionally;
(c) the operator neglects to terminate the exposure and fails to perform an adequate radiation monitoring survey before manipulating the tube assembly;
(d) there is damaged, faulty or deliberately defeated safety equipment and systems such as malfunctioning interlocks;
(e) physical damage affects the shielding or filtration.

8.2. EMERGENCY PLANNING AND PREPAREDNESS

Emergency planning and preparedness has four major components: assessment of hazards; acquisition of emergency equipment; development of written procedures; and training to deal with emergency situations, including training in handling of

emergency equipment and in following written procedures. The basic obligations, responsibilities and requirements for emergency situations are established in Safety Series No. 115 [2]. Advice and guidance on developing and implementing emergency plans are provided in IAEA Safety Series No. 91 [22], and a step-by-step method for developing integrated user, local and national emergency response capability is set forth in IAEA-TECDOC-953 [23].

Accidents in radiography may result in deterministic health effects due to loss of shielding or inadequate access control; they may also result in localized contamination from lost or stolen sources. Emergency planning starts with assessment of hazards, which involves analysis of normal conditions, how they may change during an emergency, possible types of accidents and their possible magnitudes and consequences on-site and off-site. The next step is to determine and assign the roles and responsibilities of each individual, group or organization involved in emergency preparedness and response. The plan describes the role and responsibilities of all involved in the response and also contains a brief description of the possible accidents and a concept of operation.

The responsibility for preparing the plan lies with the operating organization. Emergency procedures are to be written to deal with each foreseeable emergency. These have to be concise, easily followed instructions, describing what factors are indicative of a situation requiring emergency action, specifying the immediate action to be taken to minimize radiation exposure to persons in the vicinity of the source and the necessity for planning a course of action.

The procedures are to include the names and telephone numbers of the people identified in the emergency response, for example the radiation protection officer, the Regulatory Authority, the medical doctor, the manufacturer, the emergency services, the qualified expert and other parties, as applicable.

The operating organization is to develop capabilities needed to implement the emergency plan. This entails training of staff to deal with emergency situations including training in the handling of emergency equipment and in following written procedures.

Once a response capability has been developed, drills and exercises need to be conducted periodically. These drills and exercises provide training but also test and validate the plan, procedures and training of emergency personnel. Following the drills and exercises, deficiencies are identified and corrected. The periodic assessment includes verifying that all names and telephone numbers in the emergency procedures are still accurate and up to date and that the emergency equipment is adequate.

The operating organization is also responsible for liaison with emergency services (police, fire and medical), qualified experts and other bodies that are designated in the procedures. The purpose of this liaison is to ensure that all parties understand the hazards and are aware of the requirements of the emergency

procedures and any responsibilities for action. In the event of an accident, it is co-ordinate the response of the emergency services and other bodies, as well as to inform the Regulatory Authority.

In an emergency response, the generic response scheme designates responsible 'persons' under three specific titles:

Response Initiator,

Emergency Manager, and

Radiological Assessor.

Response Initiator — First responder on-scene

This is the person who initiates the response and performs immediate actions to mitigate the accident.

Emergency Manager

The Emergency Manager (EM) is in charge of the overall emergency response and manages the priorities and the protection of the public and emergency workers. The EM ensures that all appropriate resources have been activated.

Radiological Assessor

The Radiological Assessor is responsible for radiation surveys, dose assessment, contamination control, radiation protection support to emergency workers and the formulation of protective action recommendations. The Radiological Assessor also initiates and, in many cases, carries out source recovery, cleanup and decontamination. This position is normally held by the Radiation Protection Officer (RPO) or a hired qualified expert.

In industrial radiography, the Response Initiator is most likely to be the radiographer himself, while the EM may be the operating organization manager or a designated senior staff member. In the case of a lost source, the EM may be an appointed member of the local government. The EM is designated to be the primary spokesperson for the media. In small organizations, the radiographer may be the RPO and the EM, at the same time.

The emergency equipment has to be obtained to adequately respond to an emergency. It is suggested that the following minimum resources be made available by the operating organization:

Radiation survey instruments

(a) High range gamma survey instrument measuring dose rates up to several sieverts per hour;
(b) Low range survey instrument;
(c) Contamination monitor or probe;
(d) Check source for low range survey instruments.

Personal protective equipment

(a) Self-reading dosimeters for each team member;
(b) Permanent dosimeters for each team member;
(c) Protective overalls, overshoes and gloves;
(d) First aid kit.

Communication equipment

(a) Portable radio communications

Supplies

(a) Appropriate shielding (sufficient to attenuate the radiation significantly, for example, at least two bags of lead shot, i.e. 2 kg each for ^{192}Ir and 10 kg each for ^{60}Co);
(b) Tongs at least 1.5 m long, suitable for safely handling the source assembly;
(c) A shielded container;
(d) Appropriate hand tools;
(e) Radiation warning labels and signs;
(f) Plastic for preventing contamination of instruments;
(g) Log book.

Supporting documentation

(a) Equipment operations manuals;
(b) Response co-ordination procedures;
(c) Procedures for conducting monitoring;
(d) Procedures for personal radiation protection.

8.3. SPECIFIC EMERGENCY PROCEDURES

8.3.1. Radiographic sources

Most gamma radiography incidents involve a failure of the radiographic source to return to the shielded position. In dealing with these incidents, special equipment is necessary, and the first priority is protection of persons. In what follows, practical guidance is provided for remedial actions. The application of each procedure will depend on the specific details of each case. 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.

NOTE: The operating organization authorizes and trains different workers to implement different remedial actions within the emergency plan. Individual workers are only to implement parts of the emergency plan for which they have been authorized and trained and for which they have the appropriate equipment. For guidance, the steps are classified according to designated officers' responsibilities, i.e. radiographer, RPO or Emergency Manager.

Radiographer (Response Initiator)

(a) Recognize that an abnormal situation has occurred which might constitute an emergency;
(b) Move away from the exposed source and remain calm;
(c) Measure the radiation dose rates;
(d) Establish controlled area barriers based on dose rate limit requirements;
(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 (RPO)

(h) Plan a course of action based on previously established emergency procedures, taking into account the doses that may be received by this course of action and keeping it ALARA.
(i) Rehearse the planned course of action before entering the controlled area.
(j) Implement the planned course of action to the extent that training, equipment and authorizations allow; under no circumstances should the source be allowed to come into contact with the hands or other parts of the body.

(k) 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.
(l) Call technical assistance, if needed, from qualified experts or manufacturers.
(m) Notify the Regulatory Authority as required.
(n) When the emergency is resolved, reconstruct the accident, assess the doses received and prepare a report.
(o) Send out personal dosimeters for exposure assessment.
(p) Send the damaged or malfunctioning equipment to the manufacturer or qualified expert for a detailed inspection before reuse.

8.3.2. Missing or stolen sources or exposure devices

A missing or stolen exposure device containing the radiographic source(s) can be a significant hazard if members of the public who are not aware of the danger of radiation find it. The first priority in this type of accident will be to identify the location of the source as well as all the people who may have unknowingly handled it. Information on the type of source, its activity and other physical and chemical characteristics will be essential in assessing its potential hazard for the public. Efforts to track the source would normally start at the last known location. Investigative work is conducted to retrace the sequence of events. Reports from the medical community on possible contaminated or overexposed victims, surveys by RPO and investigation by the police are all possible sources of information on the source's whereabouts. Searching for a lost source with radiation monitoring equipment is effective for a high activity unshielded, high energy gamma source, such as industrial radiography sources. Instruments with large sodium iodide detectors are able to detect such unshielded sources at distances of up to a few hundred metres.

If a source is missing, the following items give practical guidance for remedial actions. The steps are classified according to designated officers, i.e. radiographer, RPO or Emergency Manager.

Radiographer (Response Initiator)

(a) Initiate a search immediately, using a radiation monitoring instrument. If the source has been lost in transit, retrace the planned route taken by the device and source and search visually and with the aid of radiation monitoring instruments.
(b) If it is concluded that the source is lost or stolen, notify the RPO and/or the Regulatory Authority immediately.

Radiation Protection Officer (RPO)

(c) Initiate emergency plan;
(d) When the source is found, inspect it for evidence of tampering and monitor it for shielding damage;
(e) Perform a wipe test for leakage of radioactive material;
(f) If the test results are satisfactory, the source is returned to the manufacturer or qualified expert for detailed testing;
(g) If test results are not satisfactory, initiate emergency plan.

Emergency Manager

Communicate with hospitals, the media and the public, when necessary, to help locate the missing source and, if necessary, warn of potential health effects.

Rare events have been reported involving leaking or damaged sources. If indications are that the source is damaged, see the following item.

Radiographer

(a) Immediately inform the RPO, who may require assistance from a qualified expert, manufacturer or Regulatory Authority;
(b) If instructed to do so, and wearing protective clothing (gloves), place the device and ancillary equipment in strong plastic bags to prevent spread of contamination;
(c) Place the protective clothing in a plastic bag and seal all bags used and keep the bags in a controlled area.

8.3.3. X ray equipment

In an abnormal situation involving an X ray tube assembly, assume that it constitutes an emergency so that the following steps are to be taken:

Radiographer

(a) Recognize that an abnormal situation has occurred which might constitute an emergency;
(b) Turn off the electrical power;
(c) Perform a radiation survey to confirm that the tube is de-energized;
(d) Do not move the device until details such as position, beam direction, exposure settings (tube voltage, current and time) are recorded;
(e) Inform the RPO on what has happened;

(f) Do not use the device until it is examined and repaired as necessary by a qualified expert or manufacturer.

Radiation Protection Officer

(a) Reconstruct the accident, assess the doses received and prepare a report;
(b) Send out personal dosimeters for exposure assessments;
(c) Notify the regulatory authority as required;

8.4. ACCIDENT NOTIFICATION AND REPORT

Where accident notification is required, it is important that the information provided is complete and accurate and that notification is made as soon as possible. Accidents are reported to the Regulatory Authority in accordance with the regulatory requirements or authorizations and the time-scales for notification, depending on the severity of the accident. Major radiological consequences can be avoided if actions are initiated quickly for those accidents that have broader implications for workers, the public and the environment. Notifications are to be followed up by a written accident report which includes a description of the accident, methods used to render the source of radiation safe, assessments of exposures (workers, emergency services personnel, members of the public), the cause of the accident and corrective actions. Accident reports are to be evaluated by the Regulatory Authority, in conjunction with the operating organization and the manufacturer or supplier as appropriate. The lessons learned from the accident have to be communicated to all involved, and any necessary improvements to enhance safety carried out.

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GLOSSARY

Radiography Terms and Common Abbreviations

This glossary contains terms as they are used in gamma radiography.

acute radiation syndrome. The medical term for radiation sickness.

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

camera. (See **exposure device, radiographic.**)

collimator. A small radiation shield of lead or other heavy metal used in radiography. A collimator placed on the end of the guide tube has a small opening through which a narrow cone of radiation escapes when the source is cranked into the collimator. Use of a collimator can greatly reduce the size of the controlled area to which access must be restricted.

control cable. (See **drive cable.**)

crank out cable. (See **drive cable.**)

direct reading dosimeter (**DRD**). A device worn by a person which gives instantaneous reading of the dose absorbed. These devices may be air ionization chambers or electronic devices, e.g. pocket dosimeters or pen dosimeters.

drive cable. A cable used to push out and retract a source in a cable driven exposure device. It usually operates with a crank or push–pull mechanism and is also called a control cable.

exposure device, cable operated. A radiographic exposure device where the source capsule assembly is cranked or pushed out of the shield by a cable to make the radiographic exposure.

exposure device, pneumatically operated. A radiographic exposure device where the flow of air moves the source capsule out of the shield to make the radiographic exposure.

exposure device, radiographic. A shielded container designed to hold a radiography source. A means is provided to move the source capsule assembly outside the shield or to remove part of the shield to make the radiographic exposure. Also called a radiography camera.

fixed facility. (See **shielded enclosure.**)

half-value layer. The thickness of material reducing the amount of radiation to one half of its original activity. The thickness of the half-value layer will depend on the material and the energy of the radiation.

lock box. The part of a radiographic exposure device that contains the mechanism used to lock the source capsule assembly into its safe shielded position. Also known as the 'lock assembly'.

panoramic radiographic exposure. A radiographic exposure in which film is exposed in a 360° angle around the source. For example, if the source is at the centre of a pipe, a panoramic exposure will radiograph the entire circumference of the pipe.

pigtail. The part of a radiographic source assembly that includes the short cable and the connector, but not the source capsule.

qualified expert. An individual who, by virtue of certification by appropriate boards or societies, professional licences or academic qualification and experience, is duly recognized as having expertise in a relevant field of specialization, e.g. medical physics, radiation protection, occupational health, fire safety, quality assurance or any relevant engineering or safety speciality.

radiographic exposure device. (See **exposure device, radiographic.**)

shielded enclosure (**fixed facility**). An enclosed space engineered to provide adequate shielding from ionizing radiation for persons in the vicinity. Its use allows the performance of radiography in a small, easily secured controlled area within a facility.

source assembly. The radiographic source, including the source capsule, the cable, the locking ball and the connector. In the case of the pneumatically operated and pipeline exposure devices used in this text, the assembly consists of only an inner and an outer source capsule.

source changer. A shielded container with at least two holes for sources. The old source is put into one hole of the changer, and the new source is removed from another hole.

source guide tube. A hollow tube that guides and protects the radiographic source as it is moved out of and retracted back into its shielded position in the exposure device.

survey meter. A portable instrument that measures radiation dose rate.

tenth-value layer. The thickness of material reducing the amount of radiation to one tenth of its original intensity. The thickness of the tenth-value layer will depend on the material and the energy of the gamma radiation.

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