

RADIATION SAFETY IN INDUSTRIAL RADIOGRAPHY

REGULATORY GUIDE

PAKISTAN NUCLEAR REGULATORY AUTHORITY

For Further Details

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RADIATION SAFETY IN INDUSTRIAL RADIOGRAPHY

ABSTRACT

Industrial radiography is of significant importance in non destructive testing. It involves application of ionizing radiations e.g. X-rays and gamma rays to verify the physical integrity of items, equipment and structures such as vessels, pipes, welded joints, casting and other devices. Industrial radiography poses negligible risk if it is performed in a safe manner. However, experience shows that incidents involving industrial radiography sources have sometimes resulted in high doses to workers, causing severe health consequences such as radiation burns and, in a few cases, death. Members of the public have also suffered radiation overexposures when radioactive sources used for industrial radiography are not properly controlled or regulated. All such incidents demonstrate the necessity to have effective radiation safety infrastructure in place within the facilities; complemented with strong regulatory oversight to ensure highest level of safety. In order to control/eliminate such incidents in radiation facilities, PNRA has established requirements in the form of regulations called "Regulations on Radiation Protection" (PAK/904). This regulatory guide provides guidance to the licensee(s) and worker(s) to fulfill the purpose of these regulations effectively.

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1 INTRODUCTION

The applications of ionizing radiation bring many benefits to mankind ranging from power generation to uses in medicine, industry, agriculture and research. One of the foremost industrial applications of such radiation is the use of sources to verify the physical integrity of items, equipment and structures through non-destructive testing. The structural integrity of such equipment and structures affects not only the safety and quality of the products but also the protection of the workers, public and the environment.

Radiography is a process in which radiation passes through an object/material under investigation and strikes at photographic film or some other digital detection system placed behind it. There is a partial absorption of the radiation beam as it passes through the object/material and it gives the detailed information in the form of final image on a photographic film or a digital detection system as illustrated in Figure 1.

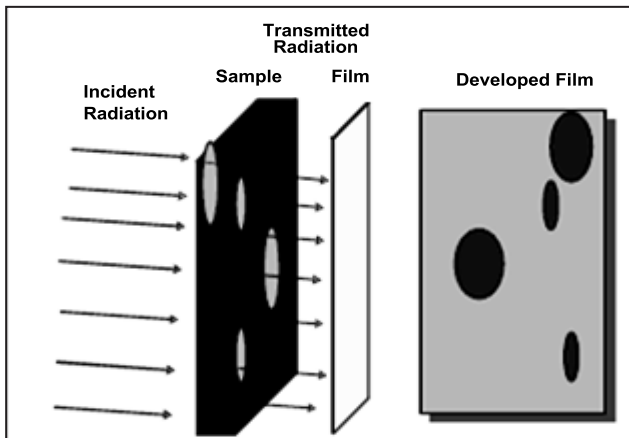


Figure 1 : Radiography Process

The ionizing radiation such as high energy gamma and X-rays are used for industrial radiography purposes worldwide because of their significant penetrating power. Apart from X-ray generators, examples of sealed radioactive sources (SRS) emitting gamma rays, used in industrial radiography, include Cobalt (Co-60), Iridium (Ir-192) and Cesium (Cs-137) etc.

Industrial radiography usually produces high doses and if a person is accidentally exposed to primary beam or comes in close contact with an unshielded radiography source (i.e. SRS), he might receive a dose that could result in severe deterministic health effects. Therefore, it requires high degree of professionalism which can only be achieved through effective management system, compliance with regulatory requirements, regulatory oversight and effective training/re-training of radiographers. A need to provide guidance to the licensee(s) of industrial radiography facilities, has been felt since long, to facilitate them in complying with the requirements regarding radiation protection. This regulatory guide has been prepared on the bases of the requirements established under regulation(s) 9, 10, 20, 25 to

30, 32 and 33 of "Regulations on Radiation Protection" - PAK/904 [1]. Moreover, guidance on the implementation of requirements of relevant regulation(s) of "Regulations on Management of a Nuclear or Radiological Emergency" - PAK/914 [2] and "Regulations for the Safe Transport of Radioactive Material" - PAK/916 [3] have also been provided in this guide.

2 OBJECTIVE

The objective of this regulatory guide is to provide guidance to licensee(s) and worker(s) regarding radiation safety in industrial radiography.

3 SCOPE

The guidance provided in this regulatory guide is applicable to the licensee(s) using radiation source(s) (i.e. SRS emitting gamma rays and X-ray generators) for the purpose of industrial radiography whether performed in a shielded enclosure or in a partially closed or open site.

4 DUTIES AND RESPONSIBILITIES

The overall responsibility for radiation safety lies with the licensee. Specific duties and the day to day responsibilities for safe operation of radiography equipment, however, lie with a range of people, including management, the radiation protection officer (RPO), radiography crew, and, for site radiography work, the client is responsible for the premises where the site radiography work is carried out. All the duties and responsibilities should be identified, in writing, and agreed to by all the relevant personnel.

The licensee is responsible for the establishment and implementation of technical and organizational measures necessary to ensure compliance with regulatory requirements and safety of the workers, public and the environment from harmful effects of radiations. The licensee should develop, implement, and maintain an overall management system of the facility that defines reporting hierarchy and responsibilities of all relevant individuals. General responsibilities of a licensee, RPO and the radiography crew may include the following:

4.1 Responsibilities of an Owner/Licensee^[4]

The owner/licensee of an industrial radiography facility should:

- i. Develop detailed operating procedures and working rules prior to commencement of industrial radiography operation for the first time;
- ii. Ensure that necessary infrastructure is available to enable the implementation of routine/emergency procedures and working rules, including provision of barriers, interlocks and warning signs;
- iii. Designate a Radiation Protection Officer (RPO) as per criteria prescribed in PNRA Regulations (PAK/904). RPO should have sufficient professional and technical

- training enabling him/her to readily comprehend and carry out assigned duties;
- iv. Ensure that the surveillance of radiography equipment is performed prior to its first use and at periodic intervals as recommended by the supplier to ensure that all interlocks, shutters and control mechanisms function normally and that no components are unacceptably worn or damaged. Surveillance record thus generated should be maintained and made available to the Authority, when required;
 - v. Ensure that if damage to equipment or variation in its radiation pattern is observed, the equipment should not be allowed to be used further until inspected by an RPO/supplier/PNRA inspector. Once repaired, the equipment should be tested for its intended function in accordance with its technical specifications, before re-use, if necessary. Record of such repairs should be maintained and made available to the Authority, when required;
 - vi. Ensure that radiation emergency plan, radiation protection program, security plan, etc. are prepared in accordance with regulatory requirements and are submitted to the Authority for review and approval. All such plans and program should be integrated into the overall management system of the facility and made available during the radiography work;
 - vii. Ensure, prior to operation of industrial radiography equipment at a site other than its own premises, that the person responsible for that site/premises is consulted and advised to:
 - a. Take necessary precautions required for workers in the vicinity, and details of the operator responsible for radiographic operation at site;
 - b. Identify the responsible person nominated for liaison between operator and other workers at site so that the directions given by the operator to maintain radiation safety are followed.
 - viii. Ensure that necessary supervision is provided in a supervised area so that workers and public are protected from potential exposure;
 - ix. Ensure that a radiography crew (i.e. operator/radiographer) is composed of technically competent individuals (other than RPO) to cater for any unforeseen incident during radiography in the shielded enclosure or open site;
 - x. Ensure that radiography crew and other facility/site personnel who may be exposed to radiation are properly instructed about radiation hazards associated with their work, and appraised of precautions necessary to limit the exposure in accordance with the dose limits;
 - xi. Ensure that no person receives radiation dose in excess of the limits specified by the Authority in regulations PAK/904, and that all radiation exposures are kept As Low As Reasonably Practicable (ALARP);
 - xii. Ensure that the measurements, investigations and assessments necessary to monitor the exposure of workers, from radiography operations, are made and relevant reports/record is maintained in a documented form;

- xiii. Ensure that source movement record/log is maintained for all the SRS under his/her control, so that an updated record of the source location is readily available.

4.2 Responsibilities of a Radiation Protection Officer (RPO)^[4]

The Radiation Protection Officer (RPO) of a facility should:

- i. Have acquired sufficient knowledge of radiation protection and of potential hazards associated with radiography equipment so that he may undertake the measurements, investigations, assessments and other duties assigned;
- ii. Be familiar with:
 - a. Applicable regulatory requirements regarding industrial radiography;
 - b. Use of radiation monitoring and personal protective equipment;
 - c. Working rules/practices and emergency procedures.
- iii. Ensure implementation of approved operating procedures and working rules during routine/emergency operations;
- iv. Instruct and train the radiography crew, as necessary, in the safe use of equipment and appropriate radiation safety measures;
- v. Ensure that each radiation worker, who may be exposed to radiation during the course of radiography, uses appropriate radiation monitoring devices, including personal dosimeter;
- vi. Ensure that all necessary personal monitoring devices and radiation survey meters are available and in good working condition and are calibrated on regular intervals;
- vii. Ensure that personal dosimeters are issued and used by all the workers and their received doses are properly assessed and record is maintained in a proper documented form;
- viii. Ensure that all the equipment e.g. radiation monitoring devices, survey meters, source containers, shutters, source control mechanisms, interlocks are inspected and tested regularly;
- ix. Ensure that the physical security requirements for source storage are properly implemented;
- x. Ensure that radiography equipment is properly stored, with the source(s) located in fully shielded position, by monitoring at appropriate intervals;
- xi. Ensure that the requirements for safe transport of radiography sources are met.

4.3 Responsibilities of Radiography Crew^[4]

The radiography crew is composed of operators/radiographers qualified and certified for conducting radiography operations. The crew is usually lead by a senior radiographer and assisted by other crew members. A senior radiographer (supervisor) should have the following responsibilities:

- i. Ensure that the crew is familiar with the basic knowledge of radiation protection;

- ii. Be familiar with radiography equipment and its use, approved working rules and applicable routine/emergency procedures and operate the equipment in accordance with approved procedures/working rules;
- iii. Ensure that source(s) (SRS/X-ray generator) movement record is maintained with the following details:
 - a. Identification number of the source(s) and/or its container;
 - b. Radioisotope and its current activity (in case of SRS);
 - c. Location of sites where the source(s) is to be used;
 - d. Date and time of source transfer/return;
 - e. Name of the person, in whose name source(s) is issued.
- iv. Ensure that all interlocks, shielding, collimator, warning signs, barriers and other protective devices are properly positioned, prior to operating the equipment, so that undue exposure of those not involved in radiography could be avoided, in particular, for partially enclosed and site radiography;
- v. Ensure that radiography equipment is not operated, if appropriate survey meter and personal dosimeter is not available;
- vi. Ensure, by using an appropriate radiation survey meter, that source (i.e. SRS) has been returned to its fully shielded position after the completion of radiography;
- vii. Ensure that source (i.e. SRS) control or shutter mechanism is locked or otherwise secured in a fully shielded position and all port plugs are firmly secured in place, while returning the gamma-radiography equipment to the store;
- viii. Ensure that radiography equipment is not operated, if it is known or suspected to be malfunctioning/deteriorated/damaged and immediately report such circumstances to the owner/licensee or RPO for appropriate corrective/investigative action;
- ix. Ensure that the operation of radiography equipment is immediately stopped, by returning the source (i.e. SRS) to its fully shielded position, in the following circumstances:
 - a. If malfunction occurs during radiography operation;
 - b. If any person other than the radiography crew enters an area where the dose rate exceeds or might exceed the allowable regulatory limits;
 - c. If the only available survey meter fails to function.
- x. Promptly take appropriate measures, in accordance with the approved emergency procedure, to bring the situation under control in the event of a radiation incident.

The assisting crew members should bear the following responsibilities:

- i. Carry out the duties/tasks as are assigned/delegated by the supervisor, in accordance with the established local rules;
- ii. Operate radiography equipment only under the direct supervision of concerned supervisor;
- iii. Take over the responsibilities insofar, in the event of a supervisor being unable to

carry out his duties, by ensuring the exposure to himself and other crew members remains within the regulatory limits.

5 INDIVIDUAL MONITORING ^[1]

Individual monitoring is a measure of radiation dose(s) to individual(s) for the estimation of exposure to radiation and the interpretation of corresponding results. Licensee/owner should ensure that radiation doses to radiography crew are assessed on regular intervals to ensure that doses are kept As Low As Reasonably Achievable (ALARA) and are below the limits of PAK/904.

Individual monitoring is recommended for the individual(s) who routinely work in a controlled area. It provides information about the magnitude and pattern of doses received by an individual. Such information is important for a number of reasons; which are described below:

- i. It enables to exercise control over radiation exposure of an individual;
- ii. It demonstrates whether doses are being kept ALARA;
- iii. It contributes to highlight unexpected high doses; enables to investigate the circumstances of overexposure; and helps to determine corrective actions to be taken, if necessary;
- iv. It indicates the efficacy of radiation protection measures applied during routine work practices and measure improvement and/or deterioration in current work practices;
- v. It also highlights good or bad work practices, status of radiography equipment, and degradation of shielding or engineered safety systems.

The ultimate choice of the type of dosimeter, to be used by the radiographers, should be made by the RPO in consultation with a qualified expert in radiation dosimetry, if possible. In addition to fulfill various technical requirements, the parameters such as its availability, initial/running cost, its robustness, and applicable regulatory requirements should also be considered while choosing a specific dosimeter.

5.1 Types of Dosimeters

Dosimeter is an instrument used for recording radiation dose to an individual. Dosimeters are used not only during routine working in a radiation area but are also used in the event of an emergency or an incident. There are two types of dosimeter which can be used for a short-term as well as for routine dose monitoring. These dosimeters are classified as active dosimeters and passive dosimeters. Necessary detail regarding these dosimeters is given below:

- Active or direct-reading dosimeters are used for short-term (from minutes up to few hours) dose assessment and provide an instantaneous dose and/or alarm at pre-set dose levels or dose-rate. These can be very useful in restricting exposures during

industrial radiography. The examples of direct reading dosimeters are Pen Dosimeters and Electronic Personal Dosimeters (EPD). Pen Dosimeters are always used after calibration through its calibrator. Active dosimeters are intended to be used for providing real time indication of the dose being received during radiography and/or for providing a warning for high dose-rate. Common measuring range of such dosimeters is from one (1) $\mu\text{Sv/hr}$ to 100 mSv/hr .

- Dosimeters used for routine monitoring are referred as passive dosimeters i.e. they require to be processed by a specialized dosimetry service provider, on periodic intervals, to assess the dose received by an individual. Examples of passive dosimeters used for dose assessment due to beta, gamma, X-rays and neutron radiations are Film Badges (FB) and Thermo-Luminescent Dosimeters (TLD). It is preferable to get such dosimeters (FB/TLD) read from an accredited dosimetry service provider on monthly basis for the assessment of dose received by the worker(s).

Figure -2 given below, illustrate the examples of various types of (active and passive) dosimeters.

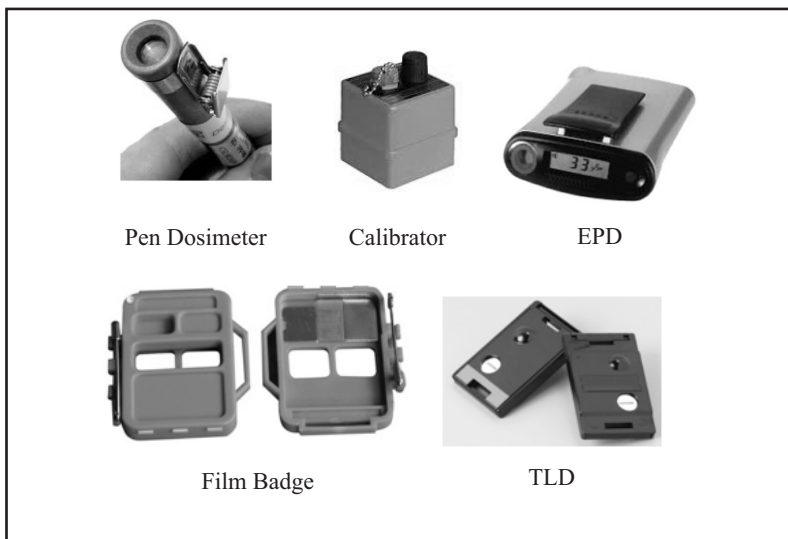


Figure 2: Types of Dosimeters

5.2 Precautions for Dosimeter(s)

To ensure that a dosimeter provides an accurate assessment of the dose(s) to a radiographer, following guidelines should be followed:

- i. Dosimeter(s) should be worn (only) by the radiographer, to whom it is issued;
- ii. It should be worn at all times, when carrying out work with radiation;

- iii. It should preferably be worn on chest or belt or in accordance with the recommendations of dosimetry service provider;
- iv. It should be worn on inside of the apron, in case if lead apron is used during work;
- v. Whenever, hands are exposed to radiation, ring dosimeters should be worn facing towards inside of the hand;
- vi. The measuring element should be correctly positioned in the dosimeter holder, both for TLD and FB;
- vii. Care should be taken to avoid damaging the measuring element of the dosimeter because of their sensitivity (i.e. dosimeters must be protected against water, high temperature/pressure and physical impact);
- viii. It should not be exposed to radiation when not being worn by a radiographer (it should be stored in an area away from radiation sources);
- ix. Dosimeter(s) (TLD/FB) should be immediately sent for processing by the dosimetry service provider after the end of each term;
- x. Damaged dosimeter should not be used. If a radiographer suspects that the dosimeter is damaged or is exposed to radiation when not in use, RPO should be informed accordingly;
- xi. The RPO should inform PNRA and the dosimetry service provider about the lost or damaged dosimeters and its replacement should be arranged as soon as possible.

5.3 Unusual Dose

Radiation doses received by radiographers are expected to be low, usually not exceeding 2-3 mSv in a year, provided that all safety measures/procedures are implemented. However, if an unusual high dose, e.g. several mSv in a year, is reported for a single dosimeter or radiographer then it is not usual and should not go unchecked. It might be the result of high workload, a maintenance activity or enactment of an emergency plan. It also indicates poor work practices or inadequate radiation protection arrangements by the licensee. Such deficiencies, if confirmed, should be rectified and reason(s) for any unusual dose should be investigated by the licensee/RPO. Records of such investigations should be maintained and PNRA should be informed accordingly.

5.4 Investigation Levels

PNRA Regulations on Radiation Protection (PAK/904) require that the licensee should establish investigation levels of dose(s) to individual(s). Such investigation levels are specific values of dose which, if exceeded, requires to be investigated. The purpose of such investigation is to determine the circumstances that gave rise to higher dose(s) and to make a judgment whether this dose is as low as reasonably achievable or not. It is important to note that the numerical value of a dose investigation level, established by the licensee, is always a fraction of a particular dose limit.

Such investigation levels and corresponding actions to be taken, in the event of these being exceeded, may also be established by the Authority. Although, they are not regulatory binding, however, their use as means of ensuring safety of workers should not be ignored.

5.5 Over Exposure

An overexposure is considered to have occurred when a particular dose limit, specified by PNRA, has been exceeded. Overexposure is most likely to occur as a result of an incident or accident. An individual or a radiographer who suspects that he had an overexposure, should immediately inform the RPO/Licensee. In case of an overexposure, the RPO/Licensee should immediately inform PNRA and carry out a detailed investigation to determine the reasons, including an assessment of dose(s) received by the individual/radiographer, and final conclusion thereof. The report of such investigation should be submitted to PNRA, as soon as possible. PNRA may also conduct further investigations, if so required.

5.6 Health Surveillance

The Licensee/owner should develop and execute a program for health surveillance of workers and should make necessary arrangements for their health surveillance [1]. Initial health surveillance should be performed to assess whether a worker possesses an adequate level of fitness for the intended tasks and that he/she is psychologically suitable to work with radiation source(s). Whereas, the licensee/owner should make arrangements for annual health surveillance (medical examination) of the workers working in a controlled area to ensure that their health remains satisfactory. Such program should be based on general principles of occupational health as described in "Factories Act 1934" currently enforced in Pakistan.

6 GAMMA RADIOGRAPHY EQUIPMENT^[5]

High activity sealed radioactive source(s), housed in a shielded exposure device, are commonly used in gamma radiography equipment. The source remains in the shielded exposure device unless used. It is exposed by remotely moving it from the shielded exposure device (e.g. by using push-pull wires) directly into an attached guide tube. It remains in the guide tube for the desired exposure time, after which it is drawn back into the shielded exposure device.

The equipment used for gamma radiography typically consists of several components such as a remote wind-out mechanism (often called a crank), connected to the radiography source (often called a 'pigtail') inside a shielded exposure device, which is directly connected to the guide tube. Sealed sources used for gamma radiography are normally part of a source assembly (the pigtail) that is usually connected to the drive cable in source projection type systems. The design and operation of these various components of gamma radiography equipment are interrelated.

Gamma radiography equipment should be selected in a way to ensure uninterrupted

operation during radiography. Following features should be considered while selection of gamma radiography equipment:

- i. It should be durable i.e. resistant to corrosion, radiation and high temperature;
- ii. It should be capable to prevent the passage of water, sand and other foreign materials into its critical parts.

6.1 Exposure Device

The exposure device (also called as gamma projector) incorporates various safety devices and features designed to reduce the risk of human error or equipment malfunction. The licensee/owner should ensure to use an exposure device that has been designed in compliance with the applicable international standards to ensure that minimum safety requirements are met and that the device and source combination is suitable for use for radiography purposes. It should be ensured that an appropriate source with maximum activity permitted is used in the exposure device (quoted for each radionuclide) for which it is designed. Since, design specifications of most exposure devices also meet the requirements for a Type B(U) transport package as specified in PNRA Regulations for the Safe Transport of Radioactive Material - PAK/916, therefore, these can also be used as transport package for the transportation of radiography source(s).

Each exposure device (gamma projector), as illustrated in Figure-3, should be permanently and clearly labeled with the following details:

- i. Radiation warning sign (trefoil) and the word "RADIOACTIVE";
- ii. Name of radionuclide and its maximum activity for which it is designed;
- iii. Name of radionuclide (SRS) in use, its serial number, activity along with reference date;
- iv. Type of container i.e. B(U) or B(M);
- v. Licensee's name, address and contact number(s) for emergency situation.

The exposure device should have a locking mechanism. The locking should be designed on the principle of "fail-to-lock", if the source is not in its secured position. It should have an indicator to show whether the device is locked or not. The exposure device should be of such design that the source can only be moved, from its secured position, by a remote control (crank). When the source is in secured position, dose rate should not exceed 2 mSv/h on the

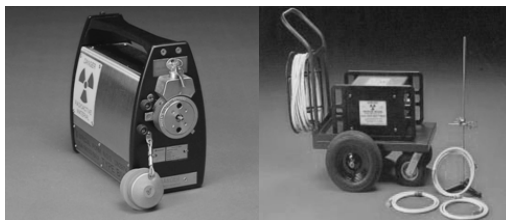


Figure 3: Exposure Device (Gamma Projector)

surface of the device and 0.01 mSv/h at a distance of one meter from the surface of the device. The remote control (crank) should also be capable to indicate clearly whether the source is in secured position or in exposed/working position.

6.2 Drive Cable and Guide Tube

Ancillary equipment such as drive cable and guide tube are used to maximize the distance between the radiographer and source i.e. SRS. It has to be ensured that drive cable and guide tube are capable to withstand with the stresses caused during the use of gamma projector. Connections between the drive cable and source, and among the lengths/pieces of guide tube should be of such design that source can move freely when connections are properly made. The source should not become loose or stuck in the guide tube. It should be ensured that guide tube and openings of the exposure device are provided with covers to prevent dust from entering into the device.

6.3 Recommendations for the Use of Drive Cable and Guide Tube

Licensee should ensure to use such gamma radiography equipment and accessories i.e. drive cable and guide tube which comply with the following recommendations:

- i. Such guide tube should be used through which the source can move freely . Design of the end cap at exposure end of the guide tube should prevent inadvertent release of the source when it is fully projected;
- ii. Open end of the guide tube should be capped to prevent ingress of dirt, grit and moisture and, if it is flexible, it should withstand repeated flexures without suffering permanent distortion. It should be capable to recover from any temporary distortion caused by a compressive load or flexure;
- iii. Exposure end of the guide tube should be clamped in position during exposure without affecting free movement of cable and source, and should be fitted with a collimator;
- iv. Where a cable is used to move the source, the coupling should ensure that during radiography work, the source (or pigtail) is not detached inadvertently;
- v. Drive cable should typically be 7-15 m and the guide tubes should be 2–6.5 m long according to the actual conditions of exposure to ensure that source is controlled from a location where dose rate is minimum;
- vi. The radiographer must know the distance through which the source is projected from its fully shielded position, through the wind out mechanism;
- vii. In case the source is moved pneumatically, the guide tube should be provided with damping mechanisms, at both ends, to protect the source from damage.

6.4 Collimators

Collimators are beam limiting devices and are used to narrow/direct the beam of radiations in a particular direction. Radiographers should ensure that collimators are used, whenever possible, to reduce radiation levels and subsequent doses. Collimators are usually

made of lead, tungsten or depleted uranium, and they can provide either panoramic or directional beams. The licensee should ensure that the collimators are compatible with the source assembly, so as to avoid the source to be stuck.

6.5 Instructions for Testing and Maintenance of Radiography Equipment

The maintenance consists of complete disassembly of the equipment and a detailed inspection of all the components. Worn or damaged parts should be replaced, wherever required, and suitable lubricant should be applied. The licensee should develop and implement a program for periodic testing/surveillance and preventive maintenance of radiography equipment and its accessories in the light of manufacturer's instructions. It should be ensured that only vendor or specially trained radiographer(s) always perform testing/maintenance of radiography equipment. Records of all maintenance, including the replacement of parts, should be kept.

Periodic testing/surveillance of the following typical items/devices should be considered in the program:

- i. Exposure device, to ensure that:
 - a. Fittings and fasteners are tight;
 - b. Locking mechanism functions properly;
 - c. Radiation levels are normal;
 - d. Connections of guide tube and remote control (crank) are secure;
 - e. Pigtail connection to drive cable is secured, using a wear gauge.
- ii. Remote control (crank) and guide tube(s), to ensure that:
 - a. Fittings are tight;
 - b. There are no indications of crushing, kinks or dents;
 - c. Drive cable can move freely;
 - d. Source (pigtail) tips are not worn through.
- iii. Safety interlock components and emergency stop devices of shielded enclosure(s), to ensure their normal operation;
- iv. Inspection of critical safety components of radiography equipment and its accessories, at least once a year;
- v. Leak test of SRS as per method and frequency recommended by the source vendor or manufacturer.

7 X-RAY RADIOGRAPHY EQUIPMENT^[4]

The most common type of X-ray generator used as radiography equipment is the conventional X-ray Tube; however, Linear Accelerators (LINACs) and Cyclotrons are also used in few specialized applications. Some typical examples of X-ray generators are illustrated in Figure-4.



Figure 4: X-ray Generator used for Industrial Radiography

X-ray generators are mostly used for performing panoramic (radial beam) and directional exposures. The X-ray tube is connected by a cable to the control panel, which provides means for pre-selection and indication of operating parameters. Dose to a radiographer can be affected by the cable length, operating parameters (volts-kV and current-mA) and local shielding around the device being radiographed. Licensee should only use such X-ray generators that satisfy the following minimum safety standards.

7.1 Electrical Safety

Electrical safety in an X-ray generator indirectly contributes to radiation safety, since electrical faults in X-ray generators can sometimes result in serious accidents with radiological consequences. In particular, all metallic items including casings, interconnecting cables, power supply unit (transformer/generator), control equipment, tube assembly, warning signals, other safety devices should be electrically bonded together (earth bonding) and connected to earth (grounded). Advice on all electrical matters, as well as on inspection and testing, should be obtained from a qualified electrical engineer or specialized service engineer, if required.

7.2 Cable Length

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

7.3 Collimators and Beam Filters

The licensee should ensure that the X-ray generators used for directional radiography should, wherever practicable, be fitted with collimators (sometimes called cones or diaphragms) to limit the beam size to the minimum compatible with the radiographic technique. Beam filters should be used to match the filtration with the work being undertaken.

7.4 Control Panel

The licensee should consider following features in a control panel while selecting an X-ray equipment. It should bear:

- i. A label incorporating radiation warning sign (trefoil), a legend indicating that X-rays are emitted when the equipment is operating and a warning label (in a local language) prohibiting unauthorized use;
- ii. A key switch to prevent unauthorized use of equipment. The key should be removable only when the switch is in 'OFF' or 'Standby' position (i.e. it should not be possible to lock the system in 'ON' condition). Key positions should be clearly marked;
- iii. A labeled warning light (fail-safe) which indicates that the equipment is powered/energized (i.e. ready to emit X-rays);
- iv. A separate labeled warning light (fail-safe) which indicates that the equipment is actually emitting X-rays;
- v. A timer that controls the exposure duration or 'ON' switch that requires continuous pressure by a radiographer to maintain the generation of X-rays;
- vi. Indicators that show the kilovolts (kV) and the current in milli-amperes (mA) when the X-ray beam is 'ON';
- vii. A clearly labeled means to immediately terminate the generation of radiation.

7.5 X-ray Tube Head

The licensee should ensure that the X-ray tube head is supported in a suitable stand or clamped in a position to prevent it from inadvertently moving. Leakage radiation (i.e. leakage that passes through the sides of the device rather than pass from the beam aperture) should be restricted by good design and construction and its level should be specified by the manufacturer. The penetrating power of leakage radiation depends on the kilo voltage and is particularly significant above 500 kV. Maximum dose rates due to leakage radiation at the surface of the device and at one (1) meter from the X ray target should be obtained from the manufacturer/vendor. Typical maximum dose rate values from leakage radiation arising from commercial X-ray tubes are up to 100 $\mu\text{Sv/h}$ at one (1) meter from the target.

7.6 Flash X-ray Units

Some X-ray based radiography equipment emit very short pulses of X-rays and the exposure duration is set in terms of number of pulses. Such radiography equipment are called flash X-ray units. These are often small, portable, battery driven units and are mainly used for the radiography of items of low density or very low wall thickness. Whereas, large such units are less often used in shielded enclosures where high output and extremely short exposure is required. The licensee should apply the same precautions that are used for ordinary X-ray equipment along with any additional safety precautions as determined on the bases of dose assessment. Most survey/dose meters are not suitable for the measurement of dose around flash X-ray units because exposure duration is extremely short and their response time is

relatively slow. Therefore, it is advisable to use suitable integrating survey/dose meters.

7.7 Inspection, Testing and Maintenance of X-ray Equipment

In order to ensure continued radiography operations, the licensee should arrange both; the routine surveillance as well as formal inspections/maintenance of X-ray equipment (including all accessories) to be performed by the manufacturer/vendor or a qualified engineer. Licensee should ensure that equipment is not modified without prior assessment of the implications of the modification on its original design and the safety assessment. Any parts to be replaced should be procured from the authorized merchant in order to ensure designed safety specifications/parameters.

The licensee should perform following periodic surveillance activities for their X-ray equipment:

- i. Checks to ensure electrical safety i.e. earth bonding and electrical insulation of cables;
- ii. Cleaning/replacing of filters, if any, of cooling system(s);
- iii. Checks to ensure there is no leakage from the X-ray tube head;
- iv. Checks to ensure that cables are in good working condition and wires are not frayed/exposed;
- v. Tests on interlocks and emergency cut-out switches;
- vi. Tests on permanently installed radiation detectors inside radiography enclosures;
- vii. Any other tests and maintenance as recommended by the manufacturer/vendor.

The licensee should establish, maintain and implement a program for maintenance of the equipment. It should be ensured that only manufacturer/vendor or specifically trained operator(s) perform such maintenance. The maintenance should be performed at least once per year or more, if the equipment is used in severe environmental conditions, such as excessive dirt, extreme humidity or is frequently moved within/outside the premises. Non-functioning or damaged parts of the equipment should be replaced at the earliest, whenever necessary. Record(s) of all maintenance activities, including replacement of parts, should be maintained and made available during the inspection(s).

8 TYPES OF INDUSTRIAL RADIOGRAPHY

Industrial radiography is carried out under a variety of exposure conditions. The radiography, with respect to exposure conditions, is generally classified into two categories i.e. radiography in a shielded enclosure (specially designed exposure room/bunker) and a site radiography (performed in the field or in a client's premises). Owner/Licensee is responsible to ensure protection of workers, public and the environment, in both the exposure situations. In addition to the responsibilities as specified in Section 4.1, following recommendations should also be implemented during both types of radiography activities:

8.1 Recommendations for Shielded Enclosure^[4,5]

A shielded enclosure is an enclosed space specially designed and engineered to provide

adequate shielding against ionizing radiations to the workers and other individuals in the vicinity. The enclosure should be designed to keep all, direct and scattered, radiations arising from radiographic exposures within itself by permitting operation of radiography equipment, from outside, by a remote means (i.e. crank or a control panel). It should incorporate engineering controls to prevent or to minimize the potential exposure of workers who might enter the enclosure when the source(s) (i.e. SRS or an X-ray generator) is exposed or energized. The licensee should ensure that industrial radiography is always performed inside a shielded enclosure, whenever it is reasonably practicable. No one should remain inside the enclosure during exposure. Following precautions should be taken for the radiography performed in a shielded enclosure:

- i. The bunker should be constructed in a way that the doors/ports, walls, floor and the ceiling, form a complete shielded enclosure;
- ii. The shielding should be sufficient to ensure that during exposure; instantaneous dose rate outside the enclosure should be in the range of 2.5 - 20 Sv/hr at one (1) foot from the walls;
- iii. Shielding and the location of enclosure should be such that no worker or a member of public should receive an effective dose in excess of 5 mSv and 1 mSv per year respectively from exposures carried out within it;
- iv. There should be a single access point for the radiography enclosure with a warning notice/sign displayed at it. A warning light should also be provided capable of illuminating during exposure and visible from outside the enclosure;
- v. Interlocks should be installed at the access point of the enclosure capable of activating a visible and audible alarm if any interlock is opened/bypassed during the exposure;
- vi. Door and panels covering access apertures into the enclosure should overlap with those apertures by a sufficient margin to prevent any leakage of radiations from the enclosure. Where a maze is used for the access, a lockable door or barrier connected to an interlock should be provided;
- vii. Since, dose rates are very high inside the enclosure, during radiography work, therefore, it should be designated as a controlled area. However, it is not required to be designated as a controlled area when it is not in use;
- viii. The enclosure should be designed in such a way that there should be no controlled area outside it. However, the area surrounding the shielded enclosure might be designated as a supervised area, if situation warrants.

8.2 Recommendations for Site Radiography^[4]

A great deal of industrial radiography operations are performed without any shielded enclosure due to economy, convenience and practical necessity. Such radiography is called as site radiography. Particular care should be exercised, during site radiography, to avoid unnecessary exposure of workers and individuals in the vicinity and to keep all the exposures as low as reasonably achievable. Collimators should be used to the extent practicable to restrict the radiation beam to the object being radiographed.

The licensee is responsible to implement following precautions for the radiography performed in an open site:

- i. Before undertaking site/field radiography, appropriate working rules should be established and adhered to at all times;
- ii. A set of site working rules should be available at site and the radiography crew should ensure that they are familiar with such rules that apply to planned exposure situations. Any modifications or additional rules to meet the particular situation should be developed in consultation with the RPO;
- iii. Before commencing radiography in an open site/field, a well-defined and clearly visible boundary should be established using warning signs, barriers, flagged rope, etc. The boundary should be located such that the calculated dose rate at the boundary during exposure should not exceed the regulatory limit of 10 $\mu\text{Sv/hr}$. Actual dose rate at the boundary should be measured during exposure using a survey meter and location of the boundary should be rectified as necessary before subsequent exposures;
- iv. The boundaries of adjacent sites/fields should not overlap each other. If overlap is unavoidable; close liaison should be maintained between radiography crew responsible for the adjacent sites to avoid accidental exposure;
- v. Control panel (or crank) should be placed at such a location that the dose rate remains as low as reasonably achievable. During exposure, the radiographer, whenever possible, should move quickly to a location where the dose rate does not exceed the regulatory limit of 25 $\mu\text{Sv/hr}$. The dose rate at the control panel, if occupied, or at the position taken up by the radiographer during exposure should be checked regularly by using a survey meter;
- vi. Immediate surroundings of the exposure device should be clearly visible from the control panel and from the position taken up by the radiographer during exposure. The area inside the delineated boundary of an open site/field should be inspected, prior to exposure, to ensure that no worker or an individual is inside it. It should be kept under observation at all the times during exposure to ensure that no one enters into it;
- vii. Appropriate warning light(s) and an audible alarm located immediately adjacent to the exposure device should be used to indicate that an exposure is underway;
- viii. Megaphone should also be made available to warn people in the vicinity not to enter the demarked area.

9 AREA CLASSIFICATION AND LOCAL RULES ^[1]

An area in which work involving radiation source(s) is undertaken is called radiation area. It is required to be specifically classified on the bases of potential for exposure to workers and individuals working in that area. It is classified into two types namely; controlled area and supervised area.

9.1 Controlled Area

The licensee should make arrangements to designate a radiation area as a controlled area

where specific protective measures or safety provisions are required for:

- i. Controlling normal exposures;
- ii. Preventing or limiting the extent of any potential exposures.

The licensee should ensure that the area where there is a likelihood of receiving an effective dose exceeding 6 mSv/year (i.e. 0.69 μ Sv/hr) or 3/10th of the annual dose limit is designated as a controlled area.

9.2 Recommendations for Controlled Area

The licensee is responsible to ensure that followings recommendations are followed by the radiation workers while working in a controlled area:

- i. A controlled area should be physically delineated. The radiation warning signs and notices clearly stating “controlled area” should be prominently displayed at all access points;
- ii. Access to controlled areas should be restricted to authorized persons only. The degree of restriction should be commensurate with the magnitude and likelihood of potential exposures;
- iii. Workplace monitoring should be carried out all around the controlled area. Suitable dose rate monitors (with measuring range from μ Sv/hr to mSv/hr) should be used for this purpose;
- iv. Arrangements should be made for calibration and testing of radiation monitoring instruments at regular intervals (preferably on annual basis); or as recommended by the Secondary Standard Dosimetry Laboratory (SSDL) or any other certified service provider;
- v. Local rules should be strictly followed, at all times, during the work in a controlled area.

9.3 Supervised Area

The licensee should make arrangements to designate a radiation area as a supervised area where occupational exposure conditions are required to be kept under review. Even though specific protection measures and safety provisions are not normally applied in a supervised area, however, exposure conditions should be kept under review.

The licensee should ensure that an area where there is a likelihood of receiving an effective dose exceeding one (1) mSv/year (i.e. 0.11 μ Sv/hr) or equivalent dose greater than 1/10th of the annual dose limit is designated as a supervised area.

Usually, all the delineated areas are controlled areas, rather than a supervised area, in industrial radiography. Supervised areas mostly exist in case of a radiography in a shielded enclosure (room/bunker) rather than the site/field radiography. For example, the area where the control panel is situated outside a shielded enclosure may often be classified as a supervised area.

9.4 Recommendations for Supervised Area

The licensee should ensure that followings recommendations are followed by workers while working in a supervised area:

- i. The extent of supervised area should also be delineated;
- ii. Appropriate radiation warning signs should be posted at all access points;
- iii. Periodic dose-rate monitoring should be carried out in and around the supervised area to ensure that working conditions are kept under review;
- iv. Established local rules should be followed during the work in a supervised area.

9.5 Local Rules

Local rules are a set of instructions that specify the manner in which the work should be carried out to ensure adequate level of protection of worker. All industrial radiography work should be carried out in accordance with a set of established local rules. It is responsibility of the licensee to establish local rules and ensure their implementation during radiography work. The licensee should ensure that these local rules describe their organizational structure and the procedures to be followed in a radiation area. These should be set down in writing preferably in local language and should be made available to all the workers involved in radiography. The format and detailed content of local rules may vary among the organizations depending on the type of radiography being undertaken and circumstances of work, however, it should include the following as a minimum:

- i. Identification of individual(s) responsible for supervision of work along with their names and designations;
- ii. Description of all controlled and supervised areas. For radiography in a shielded enclosure this may be specific to the premises where the work is carried out. However, for site radiography this may be a general description of conditions under which controlled or supervised areas are considered to exist;
- iii. General radiation safety procedures and instructions on how work should be carried out in order to keep the exposure minimum;
- iv. Value of dose investigation level (set by the Licensee/RPO) and corresponding actions/procedures to be followed in the event of that level being exceeded;
- v. Emergency plan describing actions to be taken in the event of any reasonably foreseeable incident or accident.

10 STORAGE OF RADIOGRAPHY EQUIPMENT AND SOURCES ^[5]

The licensee should ensure that the place where the radiography equipment and the sources (i.e. SRS and X-ray generators) are stored, fulfill the following recommendations:

- i. Radiography equipment should be kept in a room that is not used for any purpose other than for the storage of radiography equipment and its accessories;

- ii. The storage room should be constructed with the material of sufficient durability and strength to resist fire and unauthorized entry;
- iii. The dose rate outside the storage room should be as low as reasonably achievable and it should be ensured that dose rate inside it is less than 2.5 $\mu\text{Sv/h}$, or any member of public will not receive dose exceeding one (1) mSv per year;
- iv. The storage room should be under the control of a responsible person (e.g. RPO) designated by the licensee and should be kept locked except when removing or replacing the radiography equipment and/or sources;
- v. The log-book for the issuance of keys should be maintained;
- vi. The storage room should have a conspicuous notice bearing the word "CAUTION" and a radiation warning sign indicating that it is storage for radiography equipment and sources;
- vii. The notice, or a separate but adjacent notice, should contain instructions for contacting the responsible person (i.e. RPO) in case of an emergency;
- viii. The storage room should not be located in proximity to explosives, combustible, corrosive materials, or undeveloped photographic films;
- ix. Physical security of storage room should also be ensured. The storage room should have only one access door, so that it may not be used as a thorough fare.

11 TRANSPORT OF RADIOGRAPHY SOURCES^[3]

The deliberate physical movement of radioactive material from one place to another is called transport. PNRA Regulations on Transport of Radioactive Material - PAK/916 assign responsibilities to individuals involved in transport of radioactive materials. These individuals include:

- i. The consignor (a person or organization that prepares a consignment for transport);
- ii. The carrier (the person or organization that undertakes transport of radioactive material); and
- iii. The consignee (the person or organization that receives a consignment).

In many cases, for site radiography work, the licensee itself is responsible to perform all three functions and is required to discharge the responsibilities associated with each function.

For the transportation of a radioactive material (i.e. radiography sources) within or outside the premises, the licensee is responsible to ensure the following:

- i. Radiation monitoring should be conducted before, during and after the transportation to verify that the source is in a shielded position;
- ii. When radiography sources are to be moved within a site, for radiography work, they should be kept in the storage facility until they are ready to move to a new location. Ancillary equipment should be disconnected from the devices, and all required plugs and caps should be installed prior to movement;

- iii. The sources should be moved only in packages (i.e. exposure devices), and these should be locked and keys should be removed. If a vehicle or trolley is used to move the package, the package should be stowed or securely fastened to the vehicle or trolley so as to prevent any shift under any transport incident. The exposure devices should be kept under surveillance for the duration of movement on work location;
- iv. When sources are to be transported to another work location, for the purpose of site radiography, they should be kept in a designated storage facility until they are moved to a new location. All ancillary equipment should be disconnected and all required plugs and caps should be installed prior to transport;
- v. The licensee should ensure that the transport and the transport packages comply with the requirements of PAK/916. Where applicable, binding international instruments (i.e. codes and standards) for specific modes of transport e.g. by air or sea, should also be considered;
- vi. The package containing radiography source should be placed in a vehicle in such a way that the maximum dose rate for any person traveling in the vehicle shall not exceed $20 \mu\text{Sv/h}$;
- vii. The compartment where such package is stowed should be locked and it should not be left unattended, if placed in the back of an open vehicle, at any time during the transport;
- viii. Special arrangements for security of radiography sources, during transport, should also be made.

11.1 Actions Following Loss of or Damage to a Package During Transport

If the package containing a radiography source is damaged or appears to be damaged during transport, the licensee/owner should immediately take following actions:

- i. Person(s) responsible for safety/security of the package, at the time of incident/accident, should notify the licensee/owner and the RPO about the incident/accident;
- ii. The licensee/owner and/or the RPO should ensure that the package is carefully examined to verify that it continues to comply with transport requirements. Radiation survey should be carried out to ensure that the radiation levels at a distance of five (5) cm, at the surface and at one (1) meter from the surface of the package are within acceptable range (i.e. category of package). In case if levels are exceeded, then the established emergency procedures should be followed [2];
- iii. If package is lost or theft during transport, the person(s) responsible for its safety/security should notify the licensee/owner and the RPO, and provide all relevant information that could facilitate an early recovery of the package.

12 ACCOUNTABILITY OF RADIOGRAPHY SOURCES^[1]

Licensee should make necessary arrangements for the safety and security of the radiography sources (i.e. SRS and X-ray generators) so as to prevent the loss, theft, damage

and any unauthorized transfer or access to the sources. An accountability system, for such sources, should be established and maintained.

Formal record containing the following information about the sources, wherever applicable, should be retained:

- i. Name, identification/serial number, physical form and activity of sources with reference date (for SRS only);
- ii. Maximum tube potential difference (kV) and current (mA), or maximum X-ray energy (keV) and maximum output (dose rate);
- iii. Manufacturer, model and identification number of exposure device(s)/package(s) and/or X-ray generator(s);
- iv. Total number of sources in the custody including in use/disused SRS;
- v. Log for issuance and receipt of sources along with name of responsible person with dates;
- vi. Location of radiography work/site for which the source was issued;
- vii. Detail of disposed sources including date and method of disposal.

Through such accountability, the licensee should ensure that the locations of radiography sources are known at all times and losses are quickly identified and recovered. The record should always be kept updated and should be made available for verification during regulatory inspections. An updated inventory sheet of the sources should be submitted to the Authority biannually or earlier, if so desired by the Authority.

13 LEAK TESTING

The purpose of leak testing is to ensure that the sealed radioactive sources remain intact and that there is no leakage or dispersal of radioactive material from the housing/casing of the source. Radiography sources (i.e. SRS only) should be “leak tested” at regular intervals as specified by the Authority. It should be noted that the frequency of the leak test ranges from biannually to once in several years. For instance, typical Cobalt-60 sources of activity greater than 370 GBq (10 Ci) are leak tested at every six (6) or twelve (12) months interval. Whereas, Iridium-192 sources are not normally leak tested because of their short half lives, they are typically disused within a year.

14 EMERGENCY PREPAREDNESS AND RESPONSE^[4]

Ever increasing application of ionizing radiation in industrial radiography requires having emergency preparedness and response arrangements in place to cater for the potential radiation emergencies associated with it. In industrial radiography, accidents/incidents may result in undue exposure of workers and members of the public. PNRA regulations PAK/914 requires the licensee to develop radiation emergency plan to be implemented during the course of an emergency. The purpose of such emergency planning is to control/restrict undue exposures As Low As Reasonably Practicable (ALARP).

The concept of emergency preparedness and response is based on following major

components:

- i. Assessment of hazards
- ii. Preparation of emergency plan and procedure(s)
- iii. Acquisition of emergency equipment
- iv. Conduct of training drills/exercises
- v. Periodic review of emergency plan and equipment
- vi. Incident reporting

14.1 Assessment of Hazards

Emergency planning starts with an assessment of hazard which involves analysis of normal operating conditions, foreseeable abnormal conditions (such as equipment malfunction/failure, fire, flood, earthquake etc.), all possible types of accidents/incidents and their anticipated consequences. Experience feedback and analysis of past accidents/incidents in industrial radiography shows that most likely events involving radiography devices include, but not limited to, the following:

- i. Failure of radiographer to retract the radiography source and/or to perform pre/post job area survey
- ii. Stuck of source in the guide tube, collimator or near the entrance of the exposure container
- iii. Malfunctioning or defect in the safety control system
- iv. Entry of personnel into the controlled area during the exposure
- v. Un-intentionally energizing the X-ray machine
- vi. Spread of contamination due to leaked or damaged radiography source(s)
- vii. Handling/recovery of lost/stolen radiography source
- viii. Damage of radiography source container
- ix. Accident during transport of radiography source

All of the events enlisted above usually involve higher dose(s), in excess of the prescribed dose limits, that may cause localized exposure resulting in severe radiation injury(ies).

14.2 Preparation of Radiation Emergency Plan and Procedure(s)

Licensee is responsible to prepare its radiation emergency plan and necessary implementing procedure(s) to cater for all the foreseeable types of incidents/emergencies. It should be concise and include a description of situations requiring emergency response actions. In particular, it should specify immediate actions to be taken, to minimize radiation exposure to individuals, in the vicinity of the source/incident. The implementing procedure(s) should describe the name(s) of the response officials, their contact details and means of communication during on and off working hours. The list of individuals/organizations having a role in implementation of the emergency response plan may include the following:

- Radiation Protection Officer (RPO)

- Qualified Expert
- PNRA (NRECC/Relevant RNSD)
- Medical Doctor
- Local Administration
- Emergency Services (Rescue 1122, Fire Fighting, Local Police, etc.)
- Security Incharge of the Facility

The licensee should provide the copy of its approved radiation emergency plan and its implementing procedures to all relevant stakeholders.

14.3 Acquisition of Emergency Equipment

The licensee of an industrial radiography facility should acquire/posses sufficient equipment to adequately respond to any anticipated emergency situation. This list of necessary emergency equipment may vary, however, it is likely to include the items as given in the table below:

Table: List of Emergency Equipment

Sr. No.	Type	Items
1.	Radiation Monitoring Instruments	<ul style="list-style-type: none"> • High-Range Survey Meter (RID) • Electronic Personal Dosimeter (EPD) • Radionuclide Identification Device (RID)
2.	Personal Protective Equipment (PPE)	<ul style="list-style-type: none"> • Protective Clothing • Lead Shots/ Bricks • Long Tongs • Lead Goggles/ Gloves • Shielded Container
3.	Communication Equipment	<ul style="list-style-type: none"> • Walkie-Talkie • Mobile Phones
4.	Supplies	<ul style="list-style-type: none"> • Radiation Warning Signs • Barricading Tape • Mega Phone

In addition to the written and approved emergency plan; any supporting documents e.g. equipment operation manuals, etc. may also be included with the emergency equipment.

14.4 Conduct of Training Drills/Exercises

In order to develop the capabilities required to implement radiation emergency plan, the licensee should train its staff to deal with the identified emergency situation(s). This training may include handling of emergency equipment and implementation of radiation emergency plan and its implementing procedure(s). Once this response capability is developed, specific drills and full scope emergency exercises should be conducted periodically (preferably once in a year). Such exercises not only help in providing training to emergency response workers but also test and validate the approved radiation emergency plan of the facility. The schedule of these emergency drills/exercises should be communicated to the Authority, well in advance, so that the Authority may witness the conduct of such drills/exercises.

14.5 Periodic Review of Emergency Plan and Equipment

The licensee should conduct formal review of emergency plan and implementing procedure(s) annually to ensure that:

- i. All responsible persons within the facility and relevant off-site organizations whose role is anticipated during response to a radiological emergency have been identified and their relevant contact details (i.e. telephone numbers and fax numbers) are up to date;
- ii. Emergency equipment (as enlisted in Section 14.3) is readily available and is maintained in operable condition.

Such periodic reviews should take into account the lessons learnt from drills/exercises or in response to actual incidents/emergencies and should form the basis for revision/update of emergency response plan and/or its implementing procedures.

14.6 Incident Reporting

The licensee should notify any incident involving radiation source and warranting emergency response actions to the Authority through incident reporting performa. Such notifications should be followed up by a detailed written incident report that should include the following:

- i. Description of incident/emergency;
- ii. Actions taken to mitigate the situation, to regain the control and to restore the conditions to normal;
- iii. Root cause of the accident;
- iv. Training and experience of the personnel involved;
- v. Assessment of exposures (of the personnel involved);
- vi. Lessons learnt/ experience feedback;
- vii. Recommendations/ corrective actions.

The incident/emergency reports should be prepared by the RPO and approved by the management, before submitting to the Authority.

15 REFERENCES

1. Regulations on Radiation Protection - PAK/904
2. Regulations on Management of a Nuclear or Radiological Emergency - PAK/914 (Rev.0)
3. Regulations for the Safe Transport of Radioactive Material - PAK/916
4. Radiation Safety in Industrial Radiography, Specific Safety Guide No. SSG-11, IAEA, 2011
5. Code of Practice for the Safe Use of Industrial Radiography Equipment, Radiation Health Series No. 31, National Health and Medical Research Council, Canberra, Australia, 1989

GLOSSARY

(a) "Absorbed Dose" is a measure of energy that is deposited in a material per unit mass from any interaction with radiation. It does not take into account the nature of radiation i.e. whether it is α , β , gamma, X-ray or neutron.

The S.I. unit of absorbed dose is Joule per Kilogram (J/Kg), termed as Gray and abbreviated as Gy.

(b) "Activity" means the amount or strength of radioactive source/material. Activity (A) is the number of radioactive atoms (N) disintegrating in a unit time (t). The formal expression is:

$$A = N / t$$

S.I. unit of Activity is Becquerel (Bq), which is equal to one disintegration per second. These are expressed using a range of prefixes with the basic unit. Common multiples (prefixes) associated with activity of the sources used in industrial radiography are given in Table-1. The choice of the activity of a source depends on nature of its application.

Table 1: Multiples & Prefixes (Activity)

Multiples of Bq	Prefix	Abbreviation
1	-	Bq
1000	Kilo (K)	KBq
1,000,000 [10^6]	Mega (M)	MBq
1,000,000,000 [10^9]	Giga (G)	GBq

Although the S.I. unit of activity is Becquerel; however, the older unit i.e. Curie (Ci) is still commonly used.

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq} = 37 \text{ Gbq}$$

(c) "Dose Limits" are the set levels to prevent the occurrence of threshold, deterministic effects, and to restrict the probability of occurrence of stochastic effects to very low levels. Dose limits as prescribed in Annexure-III of PNRA Regulations on Radiation Protection, PAK/904 [1] are reproduced in Table-2 below.

Table 2: Dose Limits

Dose Limit for	Dose Quantity	Dose Limit (mSv/y)		
		Workers above 18 Years Old	Apprentices/Students (16-18 Years)	Members of the Public
Whole Body	Effective Dose	20	6	1
Lens of the Eye	Equivalent Dose	150	50	15
Extremities (Hands, Feet) &/or Skin	Equivalent Dose	500	150	50

(d) "Dose Rate" is a measure of the dose received at a location over a certain period of time.

$$\text{Dose rate} = \text{Dose} / \text{Time}$$

Dose rate is normally expressed in terms of μSv or mSv per hour and may be measured with a hand held radiation monitor.

(e) "Effective Dose" means the sum of equivalent tissue doses (H_T) each multiplied by an appropriate tissue weighting factor, (W_T). [1]

$$E = \sum W_T \cdot H_T$$

S.I. unit of effective dose is same as that of equivalent dose, i.e. the Sievert (Sv). Tissue weighting factors (W_T) used in determining effective dose are given in Table-3.

Table 3: Tissue Weighting Factors

Organ/ Tissue	W_T	Organ/ Tissue	W_T
Bone marrow	0.12	Lung	0.12
Bladder	0.04	Oesophagus	0.04
Bone surface	0.01	Skin	0.01
Breast	0.12	Stomach	0.12
Colon	0.12	Thyroid	0.04
Gonads	0.08	Brain/Salivary Glands	0.01
Liver	0.04	Remainder	0.12

(f) "Equivalent Dose" is defined as a product of average absorbed dose ($D_{T,R}$) received by a tissue (T) from radiation (R) times the radiation weighting factor (W_R) [1]:

$$H_{T,R} = W_R \cdot D_{T,R}$$

S.I. unit of equivalent dose is Joule per Kilogram (J/Kg), termed as Sievert and abbreviated as Sv. Radiation weighting factors used in determining equivalent dose are given in the Table-4.

Table 4: Radiation Weighting Factors (W_R)

Type of Radiation	W_R
β -rays, γ -rays, X-rays	1
Neutrons	5-20
α -Particles	20

(g) "Half-Life" means the time taken by a radioactive material to decay to a value which is half of its original activity and is constant for a specific radionuclide. The half lives of commonly used radiography sources (SRS) are given in Table-5.

Table 5: Half Lives

Radionuclide	Half Life
Cobalt (Co-60)	5.2 Years
Iridium (Ir-192)	74 Days
Cesium (Cs-137)	30 Years



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