Sudan University of Science and Technology
College of Gratute Studies

Radiation Protection in Industrial Radiography

الحماية من الإشعاع في التصوير الإشعاعي الصناعي

A Dissertation Submitted as Partial fulfillment of the Requirements For The Degree of Master of Science in Physics

By
Ahmed Mahdi Babekir Adam

Supervisor

Dr. Ahmed El Hassan El Faki

2017

Acknowledgement

Firstly I would like to thank my thesis supervisor Dr. Ahmed El Hassan. The door of Atomic Energy Commission- Sudan office was always open whenever i ran into a trouble spot or had a question about my research or writing. They consistently allowed this paper to be my own work, but steered me in the right direction whenever they thought I needed it.

I would like also to thank the experts who were involved in the validation survey for this research project; specially Mr.Mamoon Saquairoon Atomic Energy Commission. Without their passionate participation and input, the validation survey could not have been successfully conducted.

Finally, I must express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

Thank you

Abstract

Radiation has the power to both save and harm lives. Radiography technique is one of the most widely utilized non-destructive methods, used in industry to evaluate the structural integrity or find out the hidden details of an assembled structure. Since this method uses ionizing radiation, it is important to ensure not only the quality of product, but also the safety of the technician and the general public, as well as the protection of the environment. Since the technique deals with very large amounts of radiation during testing periods, improper practice could result in the technician and the public being exposed to a large dose of radiation in just a few of seconds.

Therefore, a high degree of care and professionalism is required for radiography work. Moreover, contamination from a corroded or damaged source can cause additional radiation hazards to radiography personnel. The radiography procedure for a job is developed in such a way that only a minimum dose is received during practice. This is achieved through the proper design of radiography exposure installation, proper training of radiation workers, strict adherence to radiation safety rules and proper selection and maintenance of radiation sources. This research deals with various aspect of radiation safety norms to be implemented during the practice.

الخلاصة

الإشعاع له القدرة على إنقاذ حياة الناس وإلحاق الضرر بهم أيضاً. تقنية التصوير بالإشعاع تستخدم بشكل كبير في طريقة من طرق الكشف غير الإتلافي, تستخدم هذه التقنية في الصناعة لتقييم الجودة أو لمعرفة التفاصيل الغير مرئية لتركيب مادة ما.

وبما أن هذه الطريقة تستخدم الإشعاع المؤين , فمن المهم ليس فقط معرفة جودة المنتج بل لسلامة تقني الإشعة , وعامة الناس بالإضافة الى حماية البيئة. وبما أن هذه التقنية تستخدم فيها كميات كبيرة من الإشعاع خلال مدة الكشف , فإن التعامل غير الجيد مع هذا الإشعاع يمكن أن يؤدي الى الفنيين وعامة الناس إلى كمية كبيرة من الأشعة في ثواني قليلة. لذلك , هناك حاجة الى درجة عالية من الاحترافية والرعاية في هذا المجال.

وعلاوة على ذلك , التلوث (تسرب الأشعة) من مصدرإشعاعي تالف أو متآكل يؤدي الى مخاطر إشعاع إضافية لفني تصوير الأشعة. يتم تحسين إجراء التصوير الاشعاعي بحيث لا يتم تلقي غير الحد الادنى من الجرعة خلال العمل.هذه العملية تتحقق من خلال التصميم الأمثل لمصادر الأشعة , والتدريب الجيد للعاملين في هذا المجال , والإلتزام بقواعد السلامة من الإشعاع, وإختيار وصيانة أجهزة المصادر المشعة بشكل جيد.

يتناول هذا البحث جوانب مختلفة من معايير السلامة الإشعاعية التي يتطلب تنفيذها خلال العمل في مجال التصوير الإشعاعي الصناعي.

Dedication

I dedicate this research work to my family who inspire me and support me all the time.

A special feeling of gratitude to my loving parent who's always being there for me, whose words of encouragement and push for tenacity nail in my fingers.

To my supervisor who guide me and help me to get through this research.

CONTENTS

Chapter One

Introduction

1.1 Background

The experience of more than 50 years of a widespread use of radioactive materials in industry, medicine, research and teaching demonstrates good practice. Safety-related events in the use and transportation of radioactive material as well as the operation of accelerators are registered. Although good practice has been established, around 1000 unusual events (incidents) have been registered since 1991. The majority of these cases occurred without any radiation exposure of individuals. One of the main branches in the industry applying radioactive sources is gamma radiography. Industrial radiography is performed under particular working conditions comprising different risks such as A- use of radioactive source with high activities.

B- Mobile application on site - often connected with difficult local working conditions.

C- No permanent surveillance by a radiation protection officer,

D- High work load and time limits for work,

E- incidents/accidents can happen in a public domain.

In summary, it can be concluded that the safety culture in this field is less developed than in other industrial branches using radioactive sources.

These characteristics may lead to incidents or deviations from normal working conditions than in other industrial branches using radioactive sources. This is shown in a recent event which happened in Louisiana / USA in June ’06 where a radiographer and his assistant may have received an effective dose of approximately 135 and 145 mSv respectively. In this case, it has to be noted that neither the radiographer nor the assistant used a survey instrument to evaluate the source location/position. Moreover, they didn’t have had turned on their required alarming rate meter. The feedback from the analysis of such events in industrial radiography is essential and shall be part of training and education of radiographers. Moreover, the competent authorities should implement a feedback process in their work, e.g. for qualifying the inspections. In addition, an important issue in industrial radiography applications is the security of the high activity source because of the mobility and the use of the equipment in public domains.

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 Objectives

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 programed 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

Introduction, background and Safety objectives are presented in Chapter one, Radiation protection and considerations are presented in Chapter two, while chapter three describes the Safety of Industrial Radiography Sources and Exposure Devices. Chapter four and five deal with Site Radiography Procedures and Storage, Movement and Transport of Radiographic Sources and Devices

1.5 Previous studies

- Khalid Khasawneh, Kun-Woo Cho Radiation protection, Its Beginnings and Development Department of nuclear and quantum engineering, Korea Advance Institute Of Nuclear Safety, Korea 1976 M J H Khan, M Rahman Shield design of concrete wall between decay tank room and primary pump room in TRIGA facilities, Atomic Energy Research Establishment, Bangladesh Atomic Energy Commission, Bangladesh September 3, 2007
- Choi, Kil-Oung;Won, Sung-Ho;Kim,Jung-Ho;Hah, Suck-Ho;Yi Development of techniques of the performance test for a radiation protection devices and it's international standards, Chul-Young;Kim 2008
- Kim, Hyun Kee Development of international education and training program for building practical competence in radiation protection; Son, Miyeon; Ko, Han-Suk 2013
- Dajie Zhuang Measurement and assessment on shielding performance of FCTC10 transport container. China institute of radiation protection July 17 ,2015.

Chapter two

Radiation Protection and Safety

2.1 Types and sources of radiation

2.1.1 Non-ionizing radiation

People use and are exposed to non-ionizing radiation sources every day. This form of radiation does not carry enough energy to ionize atoms or molecules. Microwave ovens, global positioning systems, cellular telephones, television stations, FM and AM radio, baby monitors, cordless phones, garage-door openers, and ham radios all make use of non-ionizing radiation. Other forms include the earth's magnetic field, as well as magnetic field exposure from proximity to transmission lines, household wiring and electric appliances. These are defined as extremely low-frequency (ELF) waves.

2.1.2 Ionizing radiation

Some types of radiation have enough energy that they can knock electrons out of their orbits around atoms, upsetting the electron/proton balance and giving the atom a positive charge. Electrically charged molecules and atoms are called ions. The radiation that can produce ions is called ionizing radiation.

There are many types of ionizing radiation. The following are some of the relevant ones: Alpha radiation: Alpha particles consist of two protons and two neutrons, and since they have no electrons, carry a positive charge. Due to their size and charge, alpha particles are barely able to penetrate skin and can be stopped completely by a sheet of paper.

Beta radiation: Beta radiation consists of fast moving electrons ejected from the nucleus of an atom. Beta radiation has a negative charge and is about $1/7000^{th}$ the size of an alpha particle and so is more penetrating. However, it can still be stopped by a small amount of shielding, such as a sheet of plastic. Gamma radiation: Gamma radiation is a very penetrating type of radiation. It is usually emitted immediately after the ejection of an alpha or beta particle from the nucleus of an atom. Because it has no mass or charge, it can pass through the human body, but will be absorbed by denser materials such as concrete or lead.

X-rays: X-rays are a form of radiation similar to gamma radiation but they are produced mainly by artificial means rather than from radioactive substances.

Neutron radiation: Neutron radiation occurs when neutrons are ejected from the nucleus by nuclear fission and other processes. The nuclear chain reaction is an example of nuclear fission, where a neutron being ejected from one fissioned atom will cause another atom to fission, ejecting more neutrons. Unlike other radiations, neutron radiation is absorbed by materials with lots of hydrogen atoms, like paraffin wax and plastics.

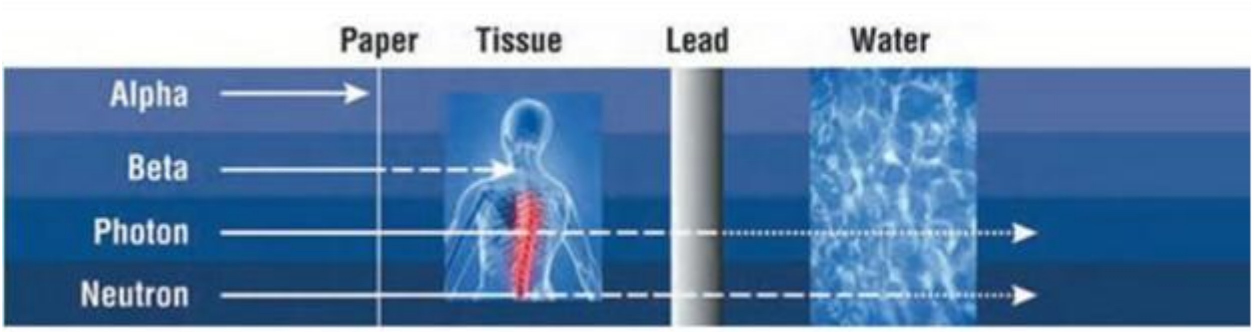


Fig (2-1)

2.1.2.1 Natural background radiation

People are constantly exposed to small amounts of ionizing radiation from the environment as they carry out their normal daily activities; this is known as natural background radiation. Radiation has always been present and is all around us. Life has evolved in a world containing significant levels of ionizing radiation.

Our bodies are adapted to it.

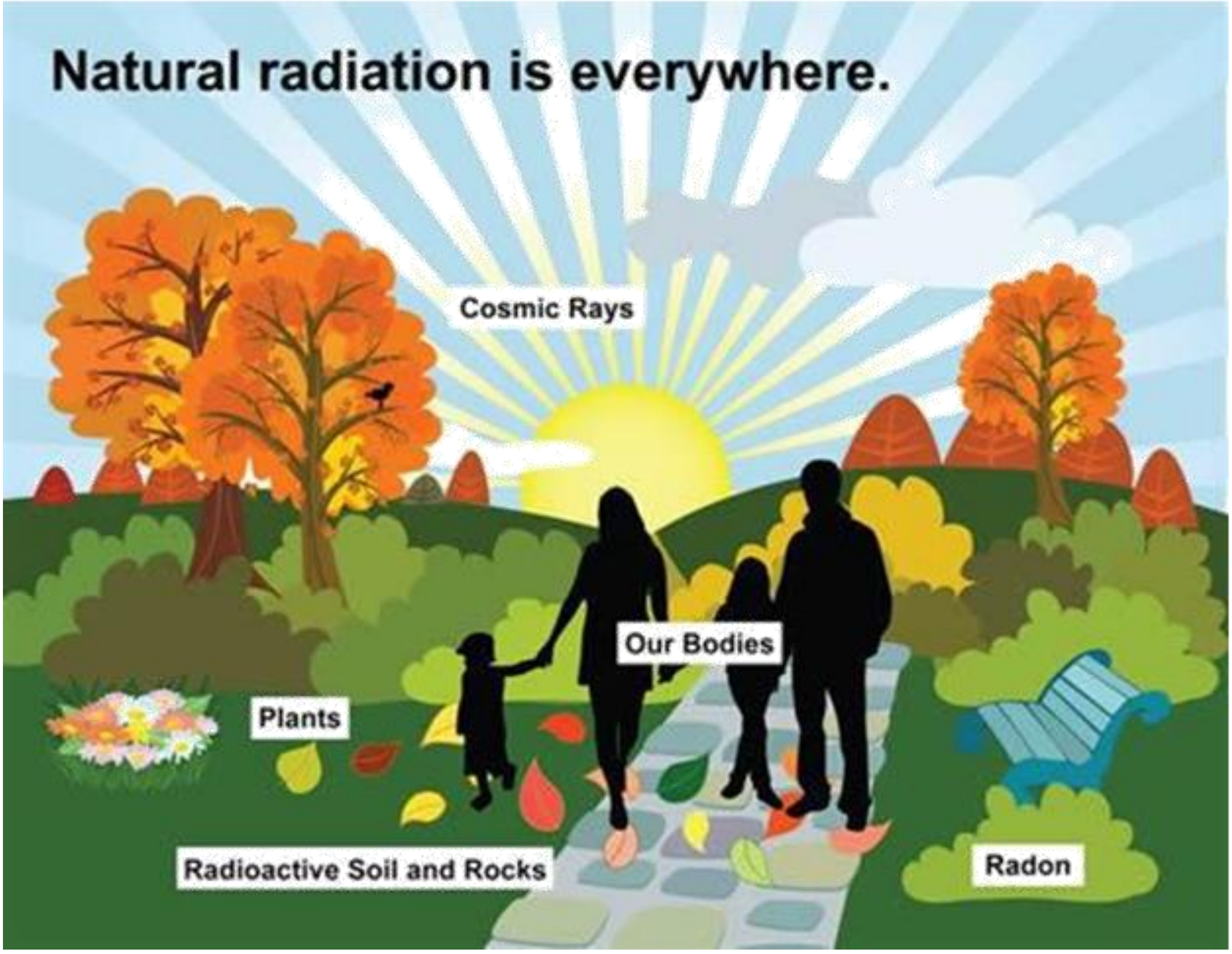


Fig (2-2)

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) identifies four major sources of public exposure to natural radiation:

A- Cosmic radiation.

B- Terrestrial radiation.

C- Inhalation and Ingestion.

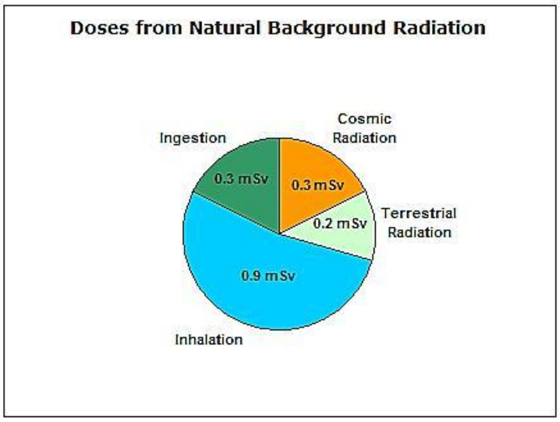


Fig (2-3) Graph-doses-from-natural-background-radiation

A- Exposure from cosmic radiation the earth's outer atmosphere is continually bombarded by cosmic radiation. Usually, cosmic radiation consists of fast moving particles that exist in space and originate from a variety of sources, including the

sun and other celestial events in the universe. Cosmic rays are mostly protons but can be other particles or wave energy. Some ionizing radiation will penetrate the earth's atmosphere and become absorbed by humans, which results in natural radiation exposure.

The doses due to natural sources of radiation vary depending on location and habit.

Regions at higher altitudes receive more cosmic radiation. The following map shows how levels of cosmic radiation vary with elevations above sea level and longitude and latitude.

B- Exposure from terrestrial radiation the composition of the earth's crust is a major source of natural radiation. The main contributors are natural deposits of uranium, potassium and thorium which, in the process of natural decay, will release small amounts of ionizing radiation. Uranium and thorium are “ubiquitous”, meaning they are found essentially everywhere. Traces of these minerals are also found in building materials so exposure to natural radiation can occur from indoors as well as outdoors.

C- Exposure through inhalation most of the variation in exposure to natural radiation results from inhalation of radioactive gases that are produced by radioactive minerals found in soil and bedrock. Radon is an odorless and colorless radioactive gas that is produced by the decay of uranium. Thoron is a radioactive gas produced by the thorium. Radon and thoron levels vary considerably by location depending on the composition of soil and bedrock. Once released into the air, these gases will normally dilute to harmless levels in the atmosphere but sometimes they become trapped and accumulate inside buildings and are inhaled by occupants. Radon gas poses a health risk not only to uranium miners, but also to homeowners if it is left to collect in the home. On average, it is the largest source of natural radiation exposure.

D- Exposure through ingestion trace amounts of radioactive minerals are naturally found in the contents of food and drinking water. For instance, vegetables are typically cultivated in soil and ground water which contains radioactive minerals. Once ingested, these minerals result in internal exposure to natural radiation.

Naturally occurring radioactive isotopes, such as potassium-40 and carbon-14, have the same chemical and biological properties as their non-radioactive isotope these radioactive and non-radioactive elements are used in building and maintaining our bodies. Natural radioisotopes continually expose us to radiation. The table below identifies the amount of radioactivity from potassium-40 contained in about 500 grams of different food products. A becquerel is a unit of radioactivity, equal to one transformation (decay) per second.

Table (2-1): potassium-40 content in food [24]

Food	Becqueral(Bq) per 500 grams
Red meat	56
Carrot	63
White potato	63
Banana	65
Lima bean	86
Brazil nut	103

The human body also contains several radioactive isotopes. The table below contains a list of some of the isotopes naturally found in the body.

Table (2-2): radioactive isotopes in the body (70 kg adult) [25]

Isotopes	Amount of radioactivity in Bq
Uranium	2.3[2,3,5]
Thorium	0.21[3]
Potassium-40	4,000[3]
Radium-266	1.1[3]
Carbon-14	3,700[3]
Tritium	23[4]
Polomium-210	40[3,5]

2.1.2.2 Artificial sources of radiation

A- Atmospheric testing the atmospheric testing of atomic weapons from the end of the Second World War until as late as 1980 released radioactive material, called fallout, into the air. As the fallout settled to the ground, it was incorporated into the environment. Much of the fallout had short half-lives and no longer exists, but some continues to decay to this day. People and the environment receive smaller and smaller doses from the fallout every year.

B-Medical sources radiation has many uses in medicine. The most well-known use is X-ray machines, which use radiation to find broken bones and diagnose disease. X-ray machines are regulated by Health Canada and provincial authorities. Another example is nuclear medicine, which uses radioactive isotopes to diagnose and treat diseases such as cancer. These applications of nuclear medicine, as well as the related equipment, are regulated by the CNSC. The CNSC also licenses those reactors and particle accelerators that produce isotopes destined for medical and industrial applications.

Fig (2-4) Gamma Camera

C-Industrial Sources radiation has a variety of industrial uses that range from nuclear gauges used to build roads to density gauges that measure the flow of material through pipes in factories. It is also used for smoke detectors, some glow-in-the dark exit signs, and to estimate reserves in oil fields. Radiation is also used for sterilization which is done by using large, heavily shielded irradiators. All these uses are licensed by the CNSC.

Fig (2-5) Nuclear Gauge

D-Nuclear Fuel Cycle nuclear power plants (NPPs) use uranium to drive a chain reaction that produces steam, which in turn drives turbines to produce electricity. As part of their normal activities, NPPs release regulated levels of radioactive material which can expose people to low doses of radiation. Similarly, uranium mines, fuel fabrication plants and radioactive waste facilities release some radioactivity that contributes to the dose of the public.

Fig (2-6)

2.1.3 Striking a Balance

Normally, there is little that we can do to change or reduce ionizing radiation that comes from natural sources like the sun, soil or rocks. This kind of exposure, while never entirely free of risk, is generally quite low. However, in some cases, natural sources of radioactivity may be unacceptably high and need to be reduced, such as radon gas in the home.

The ionizing radiation that comes from man-made sources and activities is controlled more carefully. In these settings, a balance is struck between the benefits that the radiation provides to society and the risks it imposes on people and the environment. Dose limits are set in order to restrict radiation exposures to both workers and members of the public. In addition, licensees are required to keep all radiation doses as low as reasonably achievable **(ALARA)**, social and economic factors being taken into account. Also, there has to be a net benefit to the use of radiation. For example, smoke detectors are permitted to use radioactive isotopes because smoke detectors save lives [8].

2.2 Objectives of Radiation Protection and Safety

2.2.1 Introduction

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 defenses 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 meter. 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 **S**afety **S**tandards (**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 program [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) means making every reasonable effort to maintain exposures to radiation as far below the dose limits specified in 10 **CFR**;

(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 programs:

(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 program to ensure continued safe operation. Quality assurance programs are established to review and assess, on a regular basis, the effectiveness of the overall radiation protection program 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 programs, 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].

2.3 Duties and Responsibilities

2.3.1 Introduction

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

All responsibilities and duties should be agreed to by all relevant parties and should be identified in writing.

2.3.2 The Operating Organization

A- Management of Radiation Safety and Safety Culture the operating organization, through its managers, is responsible for the establishment and implementation of the technical and organizational measures necessary to ensure protection and safety and for compliance with the relevant legal and regulatory requirements. In some cases, it may be appropriate to appoint people from outside the organization to carry out tasks or actions in relation to these responsibilities, but the operating organization retains the prime responsibility for radiation safety and regulatory compliance. A senior manager should be designated as having overall responsibility for overseeing radiation safety and verifying that industrial radiography work is carried out in accordance with regulatory requirements. Responsibilities for radiation safety are required to be established, and they should be agreed to by all relevant parties and recorded in written form. Managers should ensure that procedures are in place for the protection of workers, the public and the environment, and for ensuring that doses are kept as low as reasonably achievable (the principle of optimization). All policies and procedures should be documented, and should be made available to all staff and the regulatory body as appropriate. Managers are required to foster a safety culture within their organization, to encourage a questioning and learning attitude to protection and safety and to discourage complacency [2]. A good safety culture is promoted by management arrangements and workers' attitudes, which interact to foster a safe approach to the performance of work. Safety culture is not confined to radiation protection; it should also extend to conventional safety. Operating organizations with a good safety culture do not assign blame when incidents occur; they learn from their mistakes, foster a questioning attitude and seek continuous improvement in the safety of work processes. In investigating incidents, consideration may be given to what is acceptable behavior; however, in some cases, disciplinary measures may be taken.

B- Radiation protection program the operating organization should develop, document and implement a radiation protection program [7]. This should include information on the radiation protection arrangements, the safety assessment, the measures for implementing the arrangements, and the mechanism for the review and updating of the arrangements.

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

D- Facilities and resources the operating organization should ensure that suitable facilities and equipment are available, to enable radiography work to be carried out safely and in accordance with regulatory requirements. In particular, radiography equipment should incorporate all the relevant safety features and warning features. An adequate number of radiographers, assistants and radiation protection officers should be available to perform each job safely. They should be provided with appropriate equipment (such as radiation monitors) to enable the work to be carried out safely and effectively.

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

F- Authorization from the regulatory body the operating organization is required to apply to the regulatory body for an authorization to acquire, store, use, distribute or transfer radiography sources.

Some States may also require an authorization for the import or export of radiography sources. Radiography work should not commence until the appropriate authorization, which may impose certain restrictions or limitations, has been received by the operating organization.

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

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

(a) Information about the applicant for authorization;

(b) The operating organization's requirements for the training and qualification of all relevant staff;

(c) Technical information about the type(s) of radiation source(s) and equipment to be used;

(d) A safety assessment covering the use and storage of sources;

(e) Details of the safety system and facilities in which the radiation sources will be stored or used (e.g. shielding, interlock systems and warning systems);

(f) A radiation protection program;

(g) Emergency plans and procedures.

2.3.3 Radiation Protection Officers

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

(a) Oversight of industrial radiography operations, to assist the operating organization to comply with regulatory requirements, including requirements for the safe transport of sources for site radiography work;

(b) Maintenance of source accountancy records;

(c) Inspection and maintenance of engineering controls, safety features and warning features;

(d) Oversight of access control for controlled areas;

(e) Establishment and periodic review of arrangements for personal dosimetry, including maintenance and review of occupational dose records;

(f) Ensuring that radiographers are suitably trained in the use of equipment and in radiation protection, and that they receive regular refresher training;

(g) Ensuring that emergency plans are established and that they are practiced regularly;

(h) Supervision of workplace monitoring arrangements;

(i) Establishment, issue and periodic review of local rules (including work permits where appropriate);

(j) Investigation of higher than usual exposures and overexposures;

(k) Investigation and reporting of incidents, including accidents.

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

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

2.3.4 Qualified Experts

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

Qualified experts do not have to be employees of the operating organization: they may be appointed on a part-time basis or for specific projects.

The primary necessity is that the qualified expert should satisfy any appropriate national qualification or certification criteria.

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

2.3.5 Workers

A- Radiographers

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

Radiographers should:

(a) Follow the local rules and any relevant procedures;

(b) Wear their individual dosimeters in the correct place at all times during radiography work and source manipulation

(c) Use radiation monitors properly and in a systematic manner;

(d) Cooperate with the radiation protection officer and qualified experts on all radiation safety issues;

(e) Participate in any training concerning radiation safety;

(f) Abstain from any willful action that could put themselves or others in contravention of regulatory requirements or of the operating organization's own requirements. The radiographer should promptly inform the radiation protection officer of any incident or circumstances that could result in higher than usual radiation doses to themselves or to other persons. This could include failures or observed deficiencies in safety systems and warning systems, errors in following procedures, or inappropriate behavior. A written report should be made to the radiation protection officer as soon as practicable after the incident or observation. Radiation safety should be incorporated into the daily routine of radiography work by all personnel. This is a factor by which the overall safety culture of the operating organization should be judged.

B-Radiographers on short term contracts (itinerant workers)

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

Such working practices can create particular difficulties in relation to regulatory compliance. The relevant responsibilities of the operating organization and the itinerant radiographer should be clearly specified in the contractual arrangements.

To enable them to comply with regulatory requirements, operating organizations should be aware of itinerant workers' current annual cumulative effective dose prior to their commencing work.

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

(a) The provision of individual dosimetry and dose record keeping;

(b) Health assessment arrangements;

(c) Workplace monitoring arrangements;

(d) Local rules.

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

2.3.6 The Client

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

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

The client should not impose contractual conditions or limitations that would hinder the operating organization from performing radiography work in a safe manner. Regulatory requirements and safety requirements take precedence over commercial requirements. The client should ensure that radiography work is coordinated with other work on-site, to minimize the risks to radiographers arising from site specific hazards and to minimize radiation exposures to other workers. There should be special coordination if more than one radiography organization is working on the client's site at one time. A permit-to-work system can facilitate communication and coordination of different jobs on the same site. The client is responsible for ensuring a safe working environment for the radiographers, including the provision of scaffolding, adequate lighting and safe arrangements for working in vessels, confined spaces, trenches or other places where access might be necessary. The client is also responsible for informing visiting radiographers about safety issues that are site specific and/or providing them with any necessary training thereon.

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

Table (2-3): 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

Chapter Three

3 Safety of Industrial Radiography Sources and Exposure Devices

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

Operating organizations should ensure that equipment used for industrial radiography purposes is not modified without prior assessment of the implications of the modification for the original design and the safety assessment. The prior assessment should be reviewed by a qualified expert or by the supplier and it should be discussed with the regulatory body, to determine whether additional authorization or approval is required.

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

3.1 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 radio nuclides 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 radiographers to recognize and identify the real ones in an emergency. A sketch of a source assembly is shown in Fig(3-1).

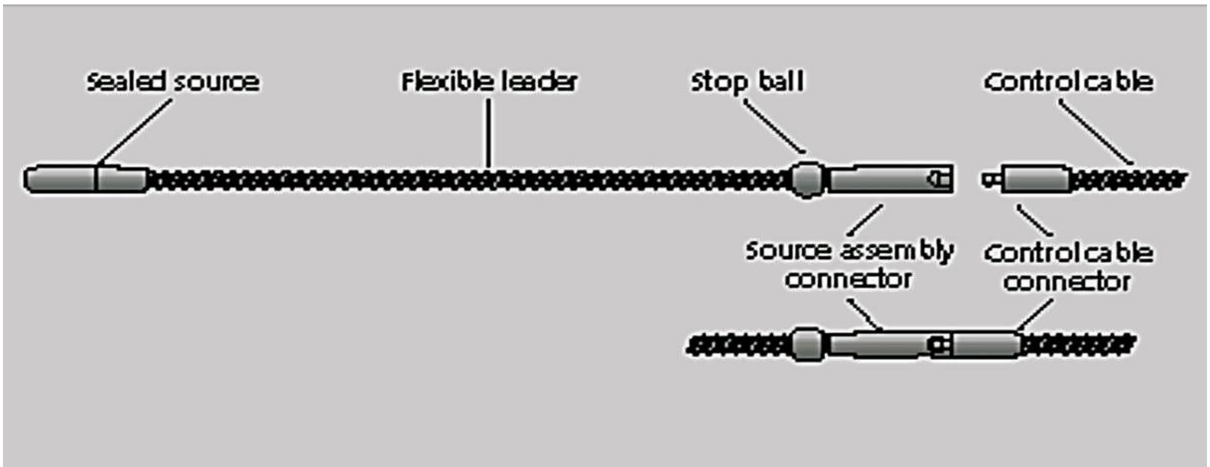


Fig (3-1). *A source assembly*

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 Standard or national requirements.

Fig (3-2) *Class **P** portable exposure device*.

Fig (3-3). *Class **M** mobile exposure devices*

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 (3-2) and (3-3) 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.

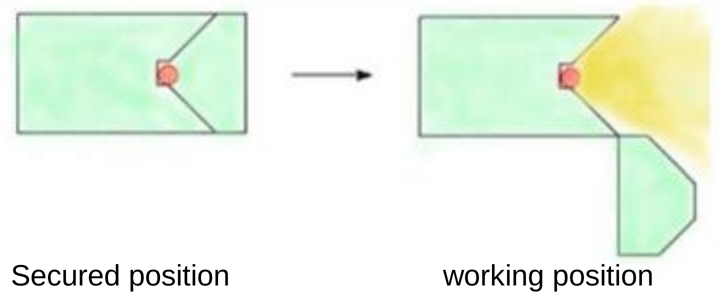
Class F: Fixed, installed exposure container or one with mobility restricted to the confines of a defined working location, such as a shielded enclosure.

The three classes of exposure container generally operate by exposing the source in one of two ways, as depicted in Figs (3-4) to (3-6).

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.



This torch-type camera uses a hinge. The radioactive source is in red, the shielding is blue/green, and the gamma rays are blue.

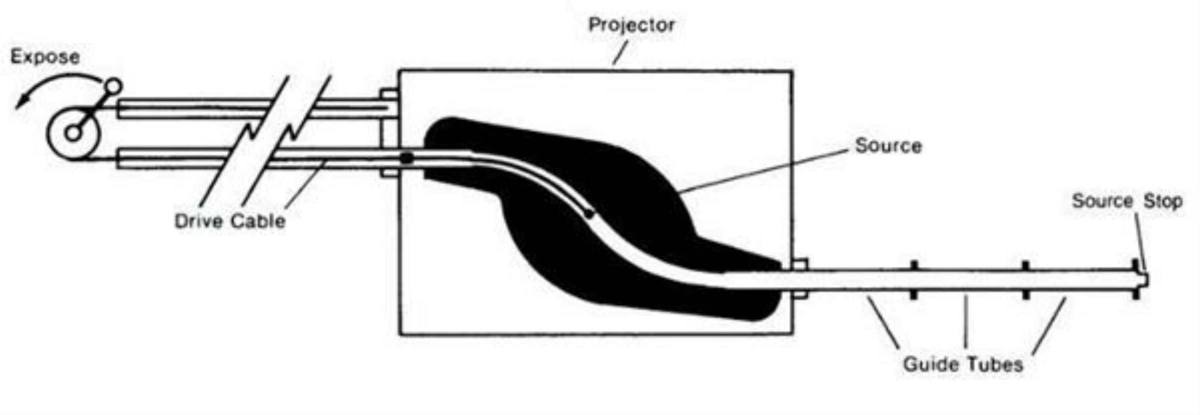
Secured position working position

This torch-type camera uses a wheel design. The radioactive source is in red, and the gamma rays are yellow

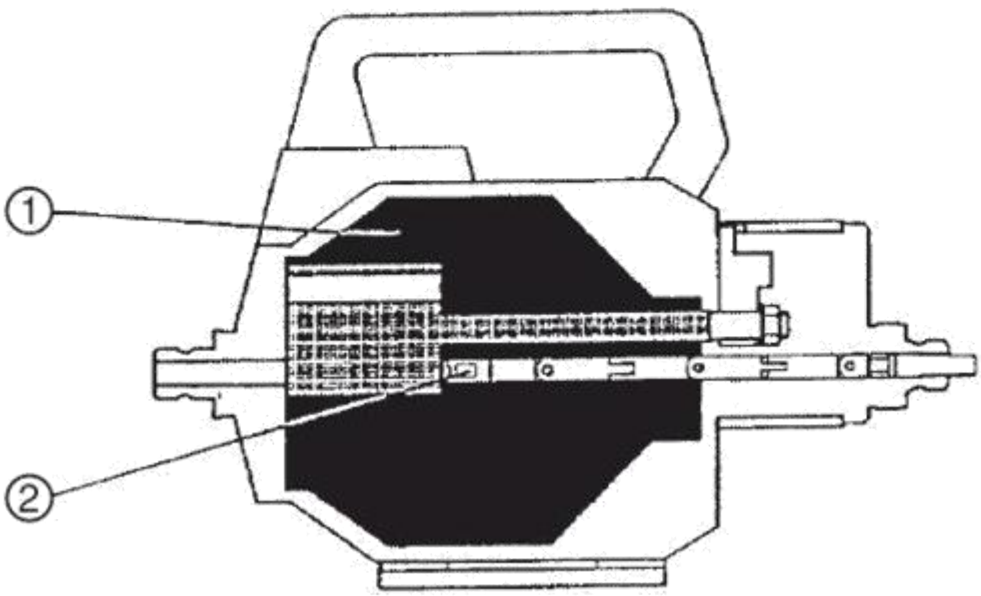
Fig (3- 4) Category I exposure device

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.



A S-shaped model



1- Shield.

2- Radioactive sealed source.

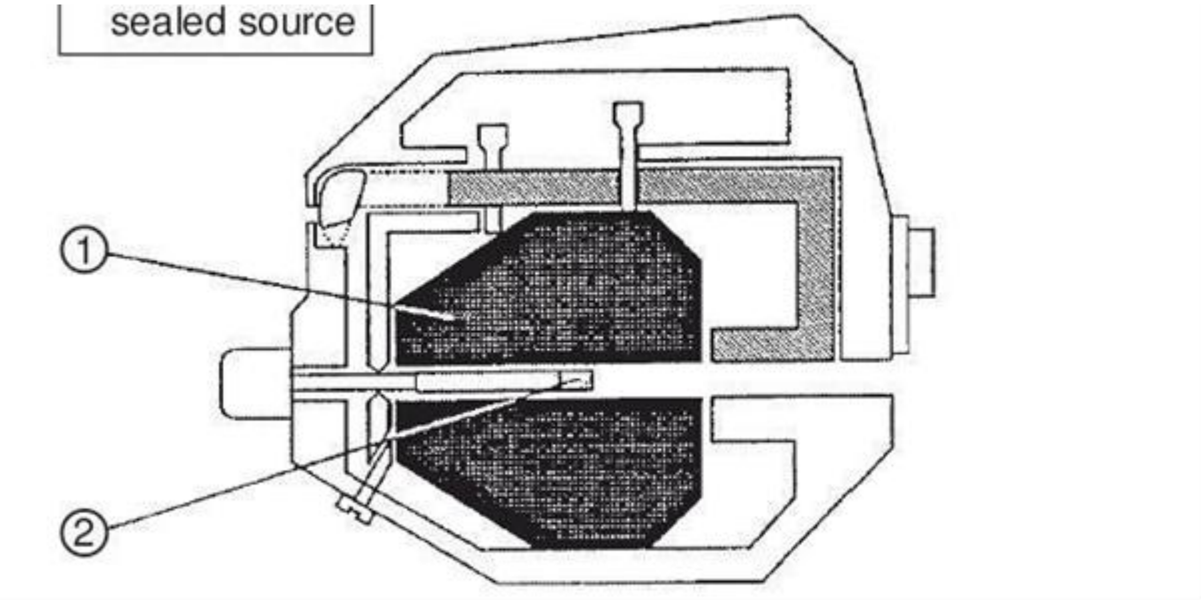


Fig (3- 5).Category II exposure container

Sealed source in fully shielded position of radiographic exposure device. The black color is the shield.

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 (3-1) 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. 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

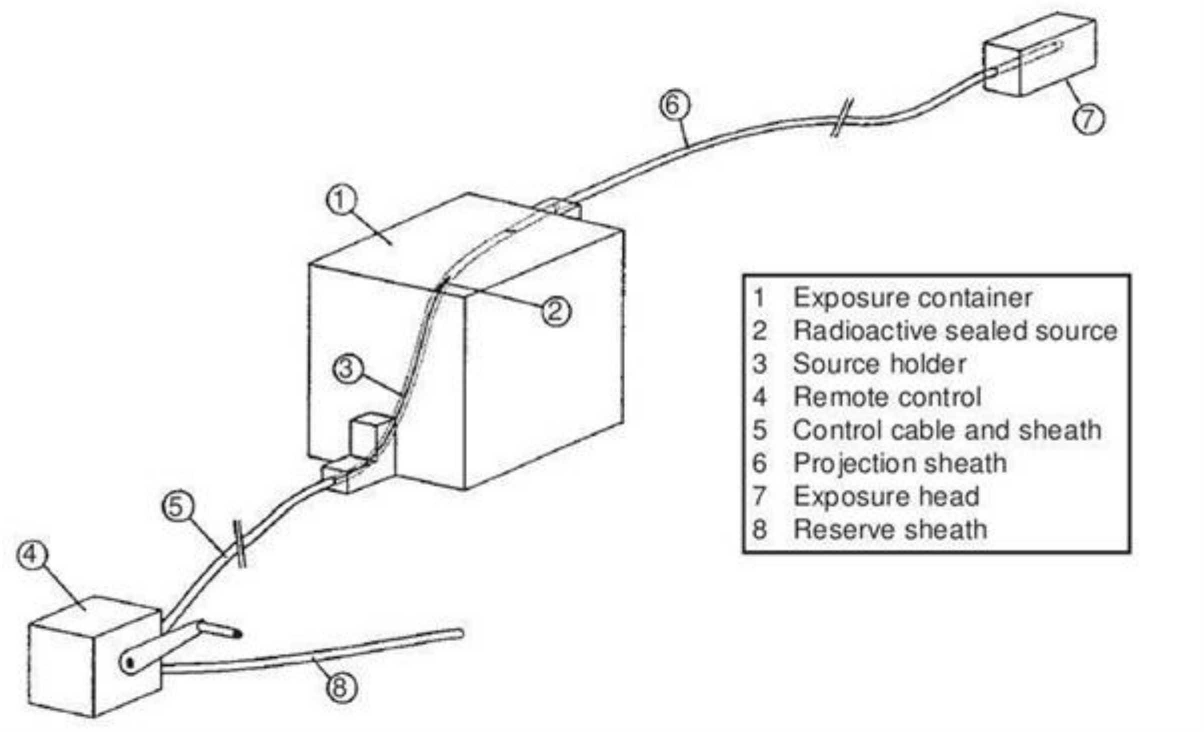


Fig (3- 6)

Table (3-1): Maximum Dose Rates Allowed per Classes of Container (ISO 3999)

Class	Maximum dose equivalent rate (μSv·h-1 (mrem·h-1))		
	On external surface of container	At 1 mm from external surface of container	At 50 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 radio nuclides in Becquerel (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 (3- 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.

3.2 X ray radiography equipment

The general requirements for 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 tube heads) are common for performing panoramic (radial beam) and directional exposures as illustrated in Figs (3-7) and (3-8). The tube assembly is connected by cable to the control panel, which provides the means for activation and operation of the ray equipment,

Fig (3- 8). Direct radiating portable X ray tube assembly

or for the pre-selection and indication of operating parameters. The dose to the radiographer is affected by the cable length, 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 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 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)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.

(b) 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.

(c) Separate labeled warning lights to indicate when the machine is energized and when X rays are being generated.

(d) 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.

(e) 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:

(a) 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 μSv. at 1 m from the target.

(b) The X ray tube assembly has a support that maintains the tube position without tipping, slipping or vibrating during the operation of the machine.

3.3 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 radio graphed 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 3-9) 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.

3.4 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 wind out (Category II containers), exposure or shutter (Category I containers) control mechanism which can be operated outside the controlled area.

Fig (3- 9) Portable ray betatron

3.5 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, 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 safter 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 (3- 10)

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 pipe liner crawler is shown in Fig (3-10), and Fig (3-11) shows the general construction.

3.6 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

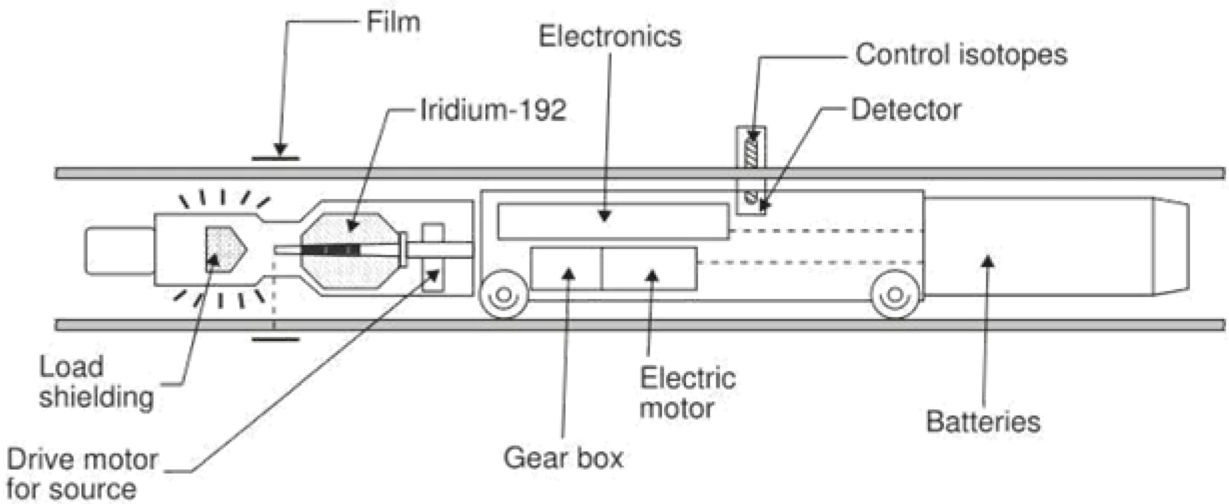


Fig (3- 11) Cross-section of pipeline crawler

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 tube head 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 (3- 12)*.

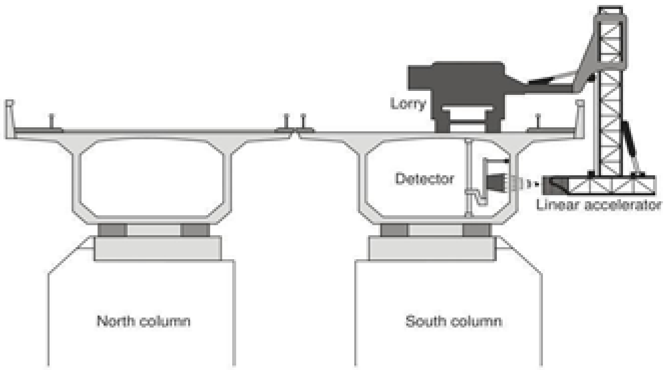


Fig (3- 12) Real time radiography (radioscopy) of a bridge

3.7 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: sub thermal, 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.

3.8 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 sitting, location, design, construction, assembly, commissioning, operation, maintenance and decommissioning of any shielded enclosure are to be based on sound engineering principles and have to

(a) Take account of regulatory requirements, approved codes and standards;

(b) Ensure protection to restrict exposures; and

(c) Be designed to prevent accidents.

Fig (3- 13) Shielded enclosure

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 (Chapter two) 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 (3- 13)*.

3.9 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 dimension 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 radio nuclides [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 (sky shine) 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 radio graphed, pipe work, 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].

(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;

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

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: gamma radiography and interlocked for ray radiography; the degree of restriction required is commensurate with the magnitude and likelihood of the exposures that would be expected.

3.10 Control of Exposure in Shielded Enclosures

A wide range of radio nuclides, source activities and 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 prevents a person from entering during an exposure, immediately interrupts the electrical power to 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 labeled 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.

Table (3-2): The warning Signs

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

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

3.11 Operation 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 thermo luminescent 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·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.

Chapter Four

4. 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 (4- 1)*.

4.1 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 μSv·. The boundary dose rates are typically in the range of 50 μSv·. when it is not possible to use a collimator. The transient dose rates during radiography source wind out 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 (4- 1)*.

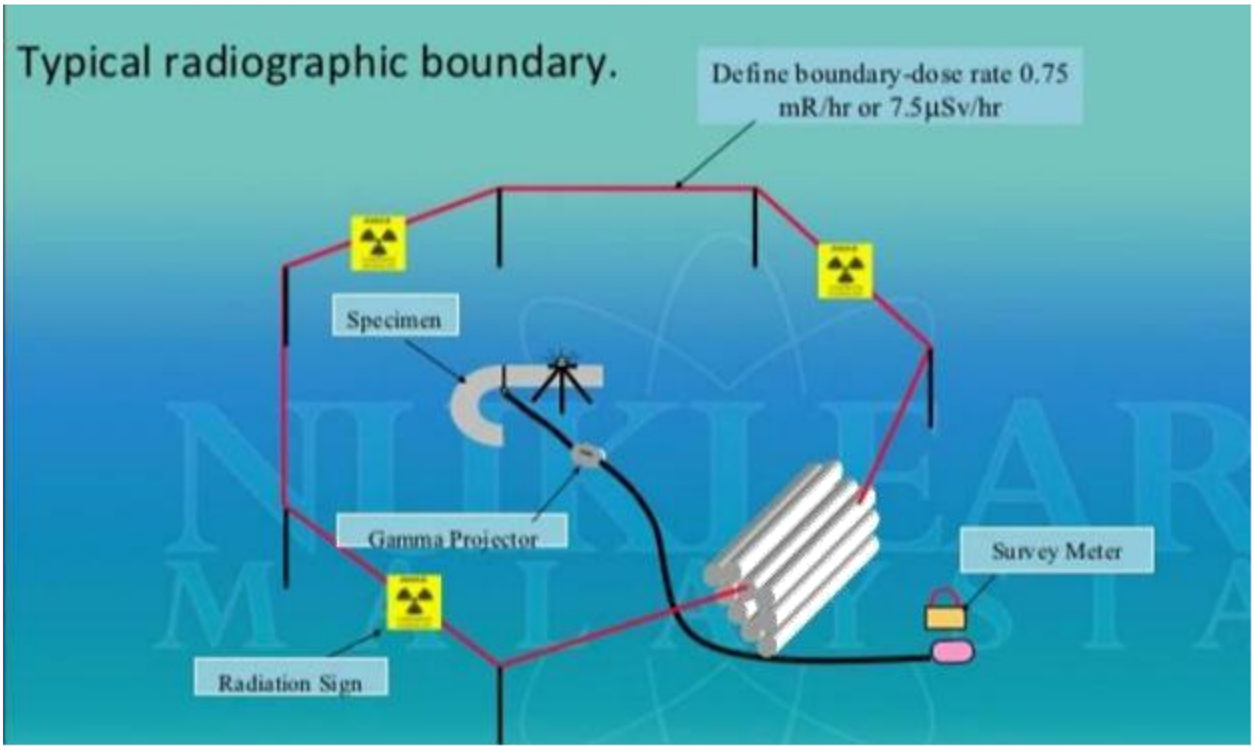


Fig (4- 1)

4.1.1. 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.

4.1.2. 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.

4.1.3. 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.

4.2 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.

4.3 Administrative Arrangement

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 m Sv. 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.

4.4. Monitoring

4.4.1. Personal dosimeters

Personal dosimeters such as thermo luminescent 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.

4.4.2. 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. 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 ray exposure control having failed.

4.4.3. 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.

4.5 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:

a- portable survey meters and personal dosimeters; b- Guide tubes, control cables and remote control; c- Collimators and local shielding;

d- Temporary barriers or tapes;

e- Warning notices and signals;

f- Emergency kit, including remote source handling tools;

g- 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 the control 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.

4.6 Additional Precautions for 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 . (240 Gy·.) from a mobile accelerator to 50 Gy (3 Gy·)
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.

4.7 Additional Precautions for Underwater Radiography

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

(a) Appropriate training of divers is necessary.

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.

4.8 Additional Precautions for Pipeline Crawler

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 μSv·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.

Chapter Five

5. Storage, Movement and Transport of Radiographic Sources and Devices

5.1 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 μSv·, 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.

5.2 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, labeling 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 program me 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.

5.3 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 a system such as malfunctioning interlocks;

(e) Physical damage affects the shielding or filtration.

5.4 Emergencies 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 a responsibility 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.

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 (**RA**)* the Radiological Assessor is responsible for radiation surveys, dose assessment, contamination control, and 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 and 10 kg each for);

(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.

5.5 Specific Emergency Procedures

5.5.1 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

5.5.2 Radiographer (Response Initiator)

Recognize that an abnormal situation has occurred which might constitute an emergency;

(a)Move away from the exposed source and remain calm;

(b) Measure the radiation dose rates;

(c) Establish controlled area barriers based on dose rate limit requirements;

(d) Prevent access to the new controlled area;

(e) Do not leave the controlled area unattended;

(f) Inform the RPO of the operating organization and the client and seek assistance.

5.5.3- Radiation Protection Officer (RPO)

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.

5.5.4 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 meters'.

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.

5.5.5 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.

5.5.6 Radiation Protection Officer (RPO)

a) Initiate emergency plan;

(b) When the source is found, inspect it for evidence of tampering and monitor it for shielding damage;

(c) Perform a wipe test for leakage of radioactive material;

(d) If the test results are satisfactory, the source is returned to the manufacturer or qualified expert for detailed testing;

(e) If test results are not satisfactory, initiate emergency plan.

5.5.7 Emergency Manager

Communicates 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.

5.5.8 Radiographer 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:

5.5.9 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.

5.5.10 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;

5.6 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, and 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.

Conclusions

By ensuring and investigating the integrity of different structures, Industrial radiographers often work at difficult or complex field sites. They transport and operate high activity, high dose rate radiation sources.

Industrial Radiographers make a valuable contribution to the society. But mishandling of industrial radiography sources can lead to high radiation dose and radiation injury.

Appropriate radiation safety training and cultivation of safety and security culture is relevant for reducing radiation accident probability.

In case of emergency, industrial radiographers are likely to be the response initiators, and may also need to take part in the recovery process.

References:

[1] International Atomic Energy Agency, Radiation Protection and the Safety of Radiation Sources, Safety Series No. 120, IAEA, Vienna (1996).

[2] Food and Agriculture Organization of the United Nations, International Atomic Energy Agency, International Labor Organization, OECD Nuclear Energy, Pan American Health Organization, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[3] International Atomic Energy Agency, Lessons Learned from Accidents in Industrial Radiography, Safety Reports Series No. 7, IAEA, Vienna (1998).

[4] International Atomic Energy Agency, Practical Radiation Safety Manual on Gamma Radiography, IAEA PRSM-1 (Rev.1), Vienna (1996).

[5] International Organization for Standardization, Sealed Radioactive Sources — General Classification, ISO/TC 85/SC 2/WG 11N 31E, ISO, Geneva (1990).

[6] International Organization for Standardization, Sealed Radioactive Sources — Leakage Test Methods, ISO/TC 85/SC 2N 390, ISO, Geneva (1988).

[7] International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Material, 1996 Edition, Safety Standards Series No. ST-1, IAEA,Vienna 2012.

[8]-http://nuclearsafety.gc.ca/eng/resources/radiation/introduction-to-radiation/types-and-sources-of radiation.cfm

[10] International Organization for Standardization, ISO 3999, Apparatus for Industrial Gamma Radiography – Specifications for Performance, Design and Tests, ISO/TC 85/SC 2N 78, ISO, Geneva (1994).

[12] Canadian Safety Code 27, Requirements for Industrial X Ray Equipment: Use and Installation, 87 EHD-130 (1986).

[13] American National Standards Institute, Radiological Safety Standards for the Design of Radiographic and Fluoroscopic Industrial X Ray Equipment, ANSI PB-270 970 (1977).

[14] British Standards Institution, Electrical Equipment of Industrial Machines, BS 2771, BSI, London (1986).

[15] British Standards Institution, Code of Practice for Safety of Machinery, BS 5304, BSI, London (1988).

[16] International Electrical Commission, Electrical Equipment of Industrial Machine — Part I, General Requirements, IEC 204-1 (1992).

[17] British Standards Institution, Recommendation for Data on Shielding from Ionizing Radiation, Part 1: 1966, Shielding from Gamma Radiation, BS 4094, BSI, London (1988).

[18] British Standards Institution, Recommendation for Data on Shielding from Ionizing Radiation, Part 2: 1971, Shielding from X Radiation, BS 4094, BSI, London (1988).

[19] International Council on Radiation Protection and Measurements, Structural Shielding Design and Evaluations for Medical Use of X-rays and Gamma Rays of Energies up to 10 MeV, NCRP Rep. No. 49, Washington, DC (1976).

[20] International Atomic Energy Agency, Schedules of Requirements for the Transport of Specified Types of Radioactive Material Consignments (As Amended 1990), Safety Series No. 80, IAEA, Vienna (1990).

[21] International Atomic Energy Agency, Emergency Response Planning and Preparedness for Transport Accidents Involving Radioactive Material, Safety Series No. 87, IAEA,Vienna (1988).

[22] International Atomic Energy Agency, Emergency Planning and Preparedness for Accidents Involving Radioactive Materials Used in Medicine, Industry, Research and Teaching, Safety Series No. 91, IAEA, Vienna (1989).

[23] International Atomic Energy Agency, Method for the Development of Emergency Response Preparedness for Nuclear or Radiological Accidents, IAEATECDOC- 953, Vienna (1997).

[24] Source: handbook of radiation measurement and protection, Brodsky, A. CRC press 1978.

[25] 2 ICRP-23 (1975), 3 Environmental Radioactivity from Natural, Industrial and Military Sources, Eisenbu d, M and Gesell T. Academic Press, Inc. 1997, 4 UNSCEAR 2000, 5 ICRP-30 (1980)