GUIDE NO. AERB/RF/SG/IARPF

GOVERNMENT OF INDIA

AERB SAFETY GUIDE

INDUSTRIAL ACCELERATOR RADIATION PROCESSING FACILITY

ATOMIC ENERGY REGULATORY BOARD

SAFETY GUIDE: AERB/RF/SG/IARPF

INDUSTRIAL ACCELERATOR RADIATION PROCESSING FACILITY (IARPF)

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Order for this Guide should be addressed to:

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FOREWORD

The Atomic Energy Regulatory Board (AERB) was constituted in 1983, to carry out certain regulatory and safety functions envisaged under Section16, 17 and 23 of the Atomic Energy Act, 1962. AERB has powers to lay down Safety Standards and frame rules and regulations with regard to the regulatory and safety requirements envisaged under the Act. The Atomic Energy (Radiation Protection) Rules, 2004, provides for issue of requirements by the Competent Authority for radiation installations, sealed sources, radiation generating equipment and equipment containing radioactive sources, and transport of radioactive materials.

With a view to ensuring the protection of occupational workers, members of the public and the environment from harmful effects of ionizing radiations, AERB Regulatory Safety Documents (REGDOCs) establish the requirements and guidance for all stages during the lifetime of nuclear and radiation facilities and transport of radioactive materials. These requirements and guidance are developed such that the radiation exposure of the public and the release of radioactive materials to the environment are controlled; the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation is limited, and the consequences of such events if they were to occur are mitigated.

The Regulatory Documents (REGDOCs) apply to nuclear and radiation facilities and activities giving rise to radiation risks, the use of radiation and radioactive sources, the transport of radioactive materials and the management of radioactive waste.

Fig. 1 Hierarchy of Regulatory Documents (REGDOCs)

Safety Codes establish the objectives and set requirements that shall be fulfilled to provide adequate assurance for safety. Safety Standards provide models and methods, approaches to achieve those requirements specified in the Safety Codes. Safety Guides elaborate various requirements specified in the Safety Codes and furnish approaches for their implementation. Safety Manuals detail instructions/safety aspects relating to a particular application. The hierarchy of Regulatory Documents depicted in Figure.1.

The recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA) are taken into account while developing the AERB REGDOCs. .

The principal users of AERB REGDOCs are the applicants, licensees, and other associated persons in nuclear and radiation facilities including members of the public. The AERB REGDOCs are applicable, as relevant, throughout the entire lifetime of the nuclear and radiation facilities and associated activities. They also form the basis for AERB's core activities of regulation such as safety review and assessment, regulatory inspections and enforcement.

The Industrial Accelerator Radiation Processing Facilities (IARPF) are required to obtain licence from AERB under Atomic Energy (Radiation Protection) Rules, 2004 for their operation. IARPFs require to obtain regulatory consents at various stages starting from the Site approval, Design and Construction approval, import or procurement of accelerator devices, operation of the IARPF, to the decommissioning of the equipment/facility and safe disposal of the radioactive sources. This safety guide, provides an approach through which compliance to the mandatory requirements can be implemented by the utilities. The requirements are given in AERB Safety Code on 'Radiation Sources, Equipment and Installations', AERB/RF/SC, 2025.

Consistent with the accepted practice, 'should' and 'may' are used in the Guide to distinguish between a recommendation and a desirable option respectively. Appendix is an integral part of the document, whereas annexure and bibliography are included to provide further information on the subject that might be helpful to the user(s).

The initial draft was prepared by an In-House Working Group (IHWG) of AERB, which was then reviewed by the Task Force (TF) with specialists drawn from technical support organizations and institutions, and other consultants.

The Comments obtained from domain experts and relevant stakeholders have been suitably incorporated. The Safety Guide has been reviewed and concurred by the AERB Advisory Committee on Nuclear and Radiation Safety (ACNRS).

AERB wishes to thank all individuals and organizations who have contributed to the preparation, review and finalization of the Safety Guide. The list of experts, who have participated in this task, along with their affiliations, is included for information.

(Dinesh Kumar Shukla)
Chairman, AERB

SPECIAL TERMS AND INTERPRETATIONS

(Specific for this Guide)

Accelerator Safety Envelope (ASE):

A set of verifiable physical and administrative credited controls that defines the binding conditions for safe operation and addresses the accelerator facility hazards and risks.

Bremsstrahlung radiation

Bremsstrahlung (or "breaking radiation") is the radiation given off by free electrons that are deflected (i.e., accelerated) in the electric fields of charged particles and nuclei of atoms.

Credited controls:

Controls determined through safety analysis to be essential for safe operation directly related to the protection of personnel and the environment.

Industrial Accelerator Radiation Processing Facility (IARPF)

A radiation processing facility containing radiation generating equipment such as an electron-accelerating device and emitting electron beam or X-rays. It also consists of associated systems used for delivering prescribed dose to a specified material/ object in a pre-set time. In an IARPF there can be more than one radiation generating source within the premises. Charge particle accelerator may have multiple beam lines as per user requirements.

Irradiation Cell

An enclosed shielded area in the irradiator where the product is irradiated.

Operation

All activities following commissioning performed to achieve, in a safe manner, the purpose for which a radiation facility is constructed.

Operator

Operator is a person who is certified in compliance with the eligibility criteria as specified by the Regulatory Body and is required to operate the facility as per written instructions and established standard operating procedures (SOP).

Radiation Processing Facility

A facility containing radiation sources and associated systems used for delivering prescribed dose to a specified material/ object in a pre-set time. GRAPF and IARPF are referred to as radiation processing facilities.

Safety Interlock

A safety interlock is an engineered device for precluding likely exposure of an individual to ionizing radiation, by removing the cause of exposure when actuated, for example, turning the particle accelerator off when the entrance door to the irradiation cell is opened, set time lag for the entrance to the irradiation room etc.

Note: Words and expressions used in this document and not defined, but defined in the Act, the Rules, and AERB Glossary shall have the meanings as assigned in the Act, Rules, and AERB Glossary.

Reader may also refer AERB Safety Code on 'Radiation Sources, Equipment and Installations' AERB/SC/RF, 2025 and AERB Safety Glossary, No. AERB/GLO, Rev.1, 2022 for Definitions of specific terms used in this Guide.

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1. INTRODUCTION

1.1 General

Radiation sources find many beneficial applications in medicine, industry, agriculture and research. At the same time, ionizing radiation sources, if not handled safely, may give rise to potential exposures leading to an unacceptable health hazard to the radiation workers as well as members of the public. Accelerators are of such kind of machines can produce radiation and will be utilised in a specific manner. The use of accelerators in various industrial applications is increasing at a rapid rate. Industrial Accelerator Radiation Processing Facility (IARPF) uses either an accelerated electron beam directly or electron beam generated high-energy photons for radiation processing of materials. These facilities are notable for absence of inventory of any radioactive source material in the plant (except any reference source meant for calibration purpose), and associated operating and handling hazards.

Generally, electron accelerators of the following types are used in an IARPF: (i) High-voltage DC accelerator from 80 keV to 5 MeV beam energy. (ii) Radio-frequency (RF) electron linear accelerator (RF Linac) having electron energies from 3 MeV upwards. The industrial applications of radiation processing are sterilization of healthcare products including pharmaceuticals, irradiation of food and agriculture products (for various end user objectives, such as phytosanitary treatment, disinfestations, shelf-life extension, sprout inhibition, pest control, sterilisation etc.) and material modifications (such as chain scission, polymer cross linking and gemstone colour enhancement etc.).

An industrial accelerator can be used in either (a) Electron beam mode or (b) X-Ray or Photon mode, at a time. In electron beam mode, the product is irradiated by the electron beam. Loss of electron beam in some target materials generates Bremsstrahlung radiation which is also used for irradiation purpose.

The high penetration ability of X-rays or Bremsstrahlung radiation is utilized for irradiating large size objects. When accelerated electrons impinge upon any material, usually high-Z element like tungsten, are used for obtaining higher efficiency of photon conversion. Radiation, thus produced in an industrial accelerator for radiation processing have a spectrum of photon energies with maximum energy being equal to maximum electron energy. The intensity of X-ray / photon is proportional to the beam power.

1.2 Objectives

This Safety Guide recommends the procedures for meeting/addressing the safety requirements for design and construction of facility, procurement of the accelerator, commissioning of accelerator, operation and periodic maintenance of the accelerator and decommissioning of the accelerator/ facility.

1.3 Scope

The Safety Guide addresses the radiological safety requirements in respect of manufacturers, suppliers and employer, operators of industrial radiation processing accelerators.

This Safety guide is concerned with radiation protection and safety, and describes methods to meet the requirements of the AERB Safety Code on "Radiation Sources, Equipment and Installations" AERB/RF/SC, 2025. A gist of applicable regulatory requirements/ approvals/licences from the AERB that should be obtained by the IARPF is given in Additional Annexure-1. The responsibilities of various stake holders of IARPF facility are given in Additional Annexure-2

For direct electron beam use, the maximum electron energy (most probable energy) should be less than 10 MeV; and for generating high energy photons, the primary electron beam energy should be less than 7.5 MeV, when using a high Z targets. A beam power of several kW is used in various radiation processing applications in an IARPF. The above energy limit is mainly based on the limit for radiation processing of food products. However, other applications of radiation processing also do not require electron energy more than 10 MeV. Hence, this document covers radiological safety requirements for electron beam accelerator up to 10 MeV in electron mode and 7.5 MeV in photon mode. Electron accelerators above 10 MeV beam energy or other than DC accelerators or RF accelerators such as microtron, betatron, rhodotron and induction-Linac should be utilized in radiation processing facility with the specific approval from Competent Authority.

This Guide does not cover technical information regarding radiation processing of specific materials. The stakeholders should follow applicable guidance/procedures of relevant authorities, governing the different types of materials to be subjected to radiation processing.

2. RADIATION PROTECTION AND SAFETY

2.1 General

Photon and electron beams produced in an accelerator facility are used mainly for radiation processing of food items, healthcare products, cables, etc. The detailed design and construction of IARPF should be based on the type of product to be irradiated, category of accelerator, the desired dose distribution in the product and the dose range attainable in the product. The design features of IARPF discussed in this guide are from the radiation safety perspective. IARPF generates electrons/ X-rays or photons which produce dose rates of the order of kGy/min at one metre from the source. The radiation shield along with design safety features (such as access door interlock to prevent any person from entering the accelerator room while the beam is ON) plays a key role in achieving protection of workers and public. Safe work practices, such as a thorough search inside the accelerator room to confirm that no one is present in the irradiation cell before the beam is switched ON, having CCTV camera system, search and secure switches and access control are essential for protection of workers and public

A Radiation Protection Programme (RPP) should be established in the institution and implemented during normal operation, for maintenance and decommissioning and in emergency situations. The employer of the IARPF is responsible for the establishment and implementation of a radiation protection programme to ensure protection and safety and compliance with the regulatory requirements. The licensee has the overall responsibility for overseeing radiation safety and verifying that IARPF is operated safely in accordance with regulatory requirements like introduction of work permit system, classification of areas, identification radiation hazards etc. The licensee should ensure that procedures are developed for the protection of workers, the public and the environment, and for ensuring that exposure to personnel is kept as low as reasonably achievable and well within the radiation dose limits prescribed by AERB. All policies and procedures should be documented, and should be made available to all staff and the AERB as appropriate. The requirements for radiation protection and the safety principles apply to the design and construction, commissioning and operation, periodic maintenance and decommissioning of IARPFs.

Implementation of the following measures should be part of the established RPP in the institution during normal operation, maintenance and decommissioning, and in emergency situations-

(i) the number of workers and the public who may receive exposure, the probability of events that may give rise to significant exposures and the magnitude of individual exposures are kept as low as reasonably achievable (ALARA) and;

(ii) A safety culture is fostered and maintained among all personnel involved in the IARPF. This is necessary to encourage a positive attitude towards radiation protection and safety and to discourage complacency / negligence.

(iii) Safety policy of the plant should be displayed at prominent place/s.

2.2 Justification

Irradiation for treatment/ exposure of materials and products with radiation or ionizing energy to change their physical, chemical or biological characteristics, to increase their usefulness and value, or to reduce their impact on the environment. Successful irradiation processes provide significant advantages in comparison to typical thermal and chemical processes, such as higher throughput rates, reduced energy consumption, less environmental pollution, more precise control over the process and the production of products with superior qualities. The most important commercial applications involve modifying a variety of plastic and rubber products, and sterilizing medical devices and consumer items. Emerging applications are pasteurizing and preserving foods, and reducing environmental pollution. Electron beam process allows for more controlled dosages to ensure only the desired property changes occur. In addition, it will obviate the need for handling high intensity radioactive sources.

2.3 Optimization

Licensee 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). The optimization process should also consider minimizing the number of individuals exposed and magnitude and likelihood of potential exposure.

As an IARPF workers are not expected to receive high doses during normal operation because of shielding. The basically optimization is more important at the time of shielding designing so that workers outside the irradiation cell area are not exposed to radiation. Also, during operation, implementation of measures such as training, radiation monitoring, work procedure, access control, interlocks, dosimetry and radiation zoning are important to prevent accidental exposure.

2.4 Dose Limits

Licensee should ensure that the exposure to personnel / worker or public due to operation of IARPF is restricted so that neither the effective dose nor the equivalent dose to tissues or organs exceeds the dose limits prescribed by the AERB. It is to be ensured that radiation doses to individual worker are assessed on a regular basis (quarterly) to ensure that the dose limits are not exceeded. The dose limits prescribed by the AERB are given in the Appendix-I.

2.5 Management for Safety

The management system of the IARPF should integrate all aspects of management so that requirements for management of radiation risks are established and applied coherently with all other requirements, including those for human performance and quality, so that radiation protection arrangements are not hampered or compromised at any time by demands such as, productivity and commercial gains. The management system also should ensure the promotion of safety culture, the periodic assessment of performance including radiation safety measures and utilising lessons learnt from experience. Safety culture includes individual and collective commitment to safety, accountability at all levels and measures to encourage a questioning and learning attitude and to discourage complacency with regard to safety. For operations that continue over long periods of time, or in the case of changed circumstances (e.g., major repair, upgrade, refurbishment), safety assessments should be reviewed and repeated and the management system updated, as necessary. Incidents and accidents have to be investigated, causative factors identified and analysed, and measures have to be taken to prevent their recurrence.

The licensee should have overall responsibility for overseeing radiation safety, and that the industrial accelerators are operated in accordance with the regulations and Standard operating procedures (SOP). Institution should prepare SOP for each equipment type, with the help of guidance from the manufacturer.

The management system should emphasise on all practical efforts needed to prevent accidents and acts with malicious intent, which may give rise to radiation risks. To ensure that the likelihood of an accident or incident having harmful consequences is extremely low, measures should be taken to prevent the occurrence of failures or abnormal conditions that could lead to loss of control of generating or managing the radiation. In addition to all the above

precautionary measures taken, an emergency preparedness and response plan should also be available to handle any emergency situation.

The primary means of preventing accidents or incidents and mitigating their consequences, as part of the safety regime, is defence-in-depth. When properly implemented, defence-in-depth ensures that no single natural, technical, human or organisational factor or failure could give rise to harmful effects and that the combinations of failures that could give rise to significant effects are of a very low probability.

3. DESIGN OF RADIATION SOURCES, EQUIPMENT AND INSTALLATION

3.1 General

The design of radiation generating equipment (accelerator) plays a major role in ensuring radiation safety. While designing/ manufacturing accelerator, adequate provision should be made to prevent any undue exposure to personnel and occurrence of an incident or emergency situations in IARPF.

Different kinds of accelerators are used in IARPF. The regulatory requirements in respect of the design and procurement of accelerators should be duly met by the manufacturer/ supplier and the employer. It should also be ensured by the licensee that the ancillary equipment/ components used in accelerator are original parts or those provided by the manufacturer/supplier and the employer.

3.2 Sealed Source

This is not applicable for this guide.

3.3 Encapsulation

This is not applicable for this guide

3.4 Source Housing

This is not applicable for this guide.

3.5 Design of Radiation Equipment

The following features should be included in the design of industrial accelerator

(i) Physical or mechanical means of disabling the main acceleration system

(ii) Maximum beam power

(iii) Built-in features for monitoring, controlling and logging critical parameters within permissible tolerance window

(iv) Built-in remote machine diagnosis

The employer should ensure that radiation generating equipment (accelerator) has necessary approval from the AERB prior to its procurement. Manufacturer/supplier of any radiation

generating equipment (accelerator) should ensure that design approval of the equipment has been obtained from AERB prior to its supply/ marketing.

3.5.1 Design Compliance of Radiation Generating Equipment

Potential exposure situations should be prevented by design features through interlocks and other safety systems which should be based on the following principles:

(i) Defense-in-depth: multiple levels of protection should be provided, thus minimizing the need for human intervention. An IARPF should only be operated if all levels of defense are in place and functioning;

(ii) redundancy: principal components important for safety should be duplicated;

(iii) diversity: to avoid common cause failures, design should have diverse means of protective measures to ensure safety; and

(iv) independence: fault in the accelerator should not impair the safety system.

Design of accelerators for radiation processing purpose should meet the requirements of relevant national/international standards[14]. Conformity of the industrial accelerators with national or international standards on electro-mechanical compatibility should be established and authenticated documents in this regard should be provided to the AERB during design approval of the device and also to the end user of the machine. Wherever feasible the compliance marking should be conspicuously displayed on the machine.

3.5.2 Fail-Safe Mechanism

The design of an accelerator should ensure that failure of a safety system inherently responds in a way that will cause no or minimal harm to other equipment, the environment or to people. The accelerator should be so designed that in the event of a breakdown or malfunction of the actuating force, or in the event of unsafe conditions, the accelerator beam should stop and should continue to remain so even if the desired condition is restored, until the appropriate protocol is operated from the control panel.

3.5.3 Safety interlocks and control system

(A) Safety Interlocks

The design of an accelerator should be such that different interlocks in the facility design should suitably be connected to the accelerator operation. Safety interlocks required in the design are personnel safety interlocks which should also include beam switch-ON interlocks, machine safety interlocks and access control system. The various types of interlocks used in the IARPF are given in Appendix-IV. The interlocks provided in the accelerator/ IARPF should follow the principle of redundancy and diversity. The general philosophy of these interlocks is as follows.

(i) Beam Switch-on Interlocks

Beam Switch Interlock is a very important system for operation of IARPF because it prevents access to the beam area while the accelerator is operating, gives a warning to occupant in irradiation area and terminates the operation of the accelerator if it produces external radiation in a work area higher than pre-set level. This should be achieved through a series of engineered safety interlocks as described below

a) Provision of limit switches to ensure complete closure of access doors before the beam is switched-on.

b) Provision in the design of the above limit switch to turn the electron beam OFF when anyone inadvertently opens the access door to the accelerator and irradiation room during radiation processing. The access doors should be designed such that they can be opened from inside the irradiation room, even when they are locked from outside.

c) Beam Window cooling: Accelerator beam ON should be interlocked with beam window cooling by air/water circulation system such that whenever beam window cooling fail, accelerator beam switches OFF.

(ii) Other Personnel Safety Interlocks

A safety interlock with entry delay to allow for reduction in ozone levels to permissible values by reversion to diatomic oxygen or removal of ozone by the ventilation system.

(iii) Machine Interlock System

a) The relevant interlocks for safe operation of accelerator such as vacuum, cooling (water, air), beam scanning, ozone blower system, SF_6 monitoring system and interlock for over current and over voltage should be available.

b) The interlocks should also be available for electron gun failure, beam scanning failure and the product conveyor movement failure.

c) An IARPF that employs transfer or conveyance system, for irradiating materials, should have a provision which either terminates the irradiation or prevents entry if an individual attempts to access the irradiation room.

(B) Access Control Systems

It should be ensured before the accelerator beam is switched ON that no one is present in the accelerator beam channel and irradiation room. This should be achieved through a few engineered layers of barrier involving design features, provision of sensors and associated instrumentation, as well as adherence to strict procedural sequencing. The philosophy of defence-in-depth should be adopted in the design of access control systems. Essential design provisions for this are outlined below:

(i) Entry into the accelerator beam channel and irradiation room should be regulated through personnel access door/s. CCTV surveillance should be provided. It should be possible for an inadvertently trapped person in radiation areas to trip and de-energize the beam operation by using “emergency trip / scram switches”.

(ii) Material and construction of the access door should be such that it can withstand fire in the plant for at least half an hour.

(iii) The product entry into /exit from zone 3 (see section 4) should be so designed that by suitable interlocks the possibility of entry by personnel is prevented.

(iv) The access control system should include a visual search procedure to clear personnel from the controlled area and high radiation areas prior to generation of radiation.

(v) It is preferred to install a public address system in zone 3 and zone 2, so that

announcement can be made before operation of machine and transport of beam to different irradiation chambers along with other emergencies like fire etc.

(C) Control Systems Design Philosophy

The accelerator control should be equipped with one or more of the following design features for the control system:

(i) A clearly identifiable and easily discernible instrumentation readout and controls on the control console. The control panel should have appropriate means to display the operating voltage (MV), beam current (mA) and beam "ON" time (sec).

(ii) A clearly identifiable switch on the accelerator control console which requires a positive, intentional action on the part of the operator for routine use in turning the particle accelerator beam ON and OFF. There should be an "Emergency shutdown switch (ESD)" on Control Console.

(iii) A password protected computer system or a single key switch or other device which will render the console inoperative when the key or device is removed.

(iv) Multiple safety interlocks at each entrance into high radiation area that shuts down the machine in the event of a breach of barrier. All safety interlocks should be designed such that any defect or component failure in the safety interlocks systems prevents the operation of the accelerator.

(v) Circuitry such that each personnel safety interlocks should allow its individual operation independent of all other interlocks.

(vi) A scram button or an easily identifiable emergency power cut off switch located at all high radiation areas (such a cut-off switch should include manual reset so that accelerator cannot be restarted from the accelerator control console without resetting the cut-off switch).

(vii) When the safety interlock system has been tripped, it should only be possible to resume operation of the accelerator by manually resetting controls at the position where safety interlock has been tripped and lastly at the main control

console.

3.5.4 Conventional safety

The design of the accelerator should be in compliance with the conventional safety requirements, e.g., concerning high voltage power supply, as required by relevant authorities. All equipment inside the irradiation room of the facility including wiring, electrical equipment, lighting, etc. should be selected so as to minimise failure due to prolonged exposure to radiation.

3.6 Shielded Enclosure

3.6.1 Structural Shielding

(i) In an IARPF, design of radiation shielding is the most important feature. The radiation shielding should be such that, when the accelerator is operated at its maximum rating, the radiation dose in full occupancy areas outside the accelerator and irradiation vaults does not exceed the applicable dose limit (1mSv for public and 20 mSv for occupational exposure in a year).

(ii) Concrete used for the construction of the irradiation room should have a minimum density of 2.5 $g.cm^{-3}$. Adequate compaction should be ensured during pouring of concrete into the walls to avoid any void formation.

3.6.2 Control Room

Control Room should be made accessible during beam ON mode with appropriate administrative controls in place. Appropriate personnel radiation monitoring should be provided for workers in this area during beam ON mode. In the control room, the dose rate during beam 'ON' should be such that the occupational dose limit of 20 mSv in a year is not exceeded.

Personnel entry door leading to the accelerator beam room/ irradiation room should be made preferably through control room. In case the personnel entry door to the accelerator beam room is situated outside the control room, large glass windows should be provided in the control room or the control room should have glass walls so that visibility to the entrance of the irradiation room is available at all times. Cameras should be provided for monitoring the accelerator and irradiation areas and entry/ exit points to these areas and they should be monitored from the Control Room. The cameras to be used in the high-radiation areas should

be capable of functioning even when subjected to continuous radiation exposure over prolonged periods.

3.6.3 Conduit/Opening

In an IARPF, conduits/ openings are made in the walls of the radiation shield for purposes such as,

(i) to pass service cables/ electric cables to various components of the IARPF

(ii) to allow products (e.g., polymer cables, polymer sheets, material filled in boxes etc.) into the irradiation room for radiation processing.

Such penetrations/ openings provided in the radiation shielding should be designed such that there is no direct streaming of radiation and the dose rate outside the shielding are such that the regulatory dose limits are not exceeded. The openings for product entry/exit should not be large enough to allow persons to enter the irradiation room or should have suitable design features to prevent entry of persons. Cameras for continuous monitoring of such locations (when IARPF is in operation) should form a part of the safety systems.

3.6.4 Audio-Visual Indicators

In order to alert/caution the personnel inside the facility about the operational status, a number of warning systems should be in place. For example:

(i) A notification system comprising indicative signs and labels, voice announcements and warning sirens through a public address system should be in place to caution the personnel.

(ii) An appropriate intercom facility supported by UPS should be available in the irradiation room for facilitating communication between the control room and other areas.

(iii) Audio-visual warning signal should be displayed and annunciated in the irradiation room area whenever the accelerator beam is turned ON.

(iv) CCTV cameras should be put at vantage locations for safety as well as for surveillance.

(v) Locations with radiological hazards should be demarcated from other areas by posting appropriate symbols, caution boards etc. indicating dose rate in work areas and

precautions to be taken by working personnel.

(vi) Instructions stating do's and don'ts in case of emergencies should be posted at all appropriate locations in the facility along with the telephone numbers of personnel who should be contacted in the event of an emergency.

(vii) Appropriate power back-up should be provided to the illumination arrangement in all critical areas such as radiation areas, emergency exits, passages and the control room as well as to all alert and caution systems so as to enable safety related systems to be active under power breakdown.

3.6.5 Fixed Area Monitor

The facility should be equipped with area radiation monitoring devices *(Fixed area monitor*) to detect photons (*capable of measuring dose rate as low as 1µSvh^{-1} with minimum increment of 0.1µSvh^{-1}*) with pre-set alarms installed at the control room, product entry/exit area etc. The readings of these fixed area monitors should be telemetered to the control room. In present days, IOT based protocol is available and can be utilised for radiation monitoring system to access data remotely.

3.6.6 Radiation Symbol and Warning Sign at Entry point

(i) The radiation symbol specified in the safety directive issued by the AERB should be conspicuously posted at the entrance of every access door in the work areas comprising three zones as specified in Section 4. Specifications of radiation symbol and warning sign are provided in the safety directive issued by the AERB, which is reproduced in Appendix-II. A placard indicating 'RADIATION: RESTRICTED ENTRY' should be posted together with its equivalent in Hindi as well as in the local language, alongside the radiation symbol.

(ii) The status of the accelerator in the IARPF (Accelerator OFF, Accelerator Ready to Operate, Accelerator ON) should be displayed at various locations such as the control room, personnel entry door and product loading/ unloading area with an audio-visual warning.

(iii) An amber indicator lamp should be provided on the control panel to indicate the "ready to operate" condition of the accelerator. A red indicator lamp should be provided on the

control panel and should be automatically illuminated when the beam is ON. A green indicator lamp should be provided on the control panel and should be automatically illuminated when the beam is OFF. These lamps should replicate the above functions on the accelerator housing. A hardwired interlock should be provided such that if the 'beam ON' indicator lamps fails, then the device cannot be energized, and replacement of the lamp should not automatically re-energize the device. Only manual resetting should re-energize the device.

3.6.7 Ventilation systems

(i) Ozone (O_3) and Nitrogen oxides (NOx) and other toxic gases generated during radiation processing should be continuously scavenged by means of a suitable ventilation system to minimize the concentration in the irradiation cell and likely gaseous diffusion into the occupied areas.

(ii) Adequate ventilation in the irradiation room should be achieved by providing forced fresh air supply through grills/louvers and incorporating exhaust fans in the system. Two exhaust fans (one operational, one standby) should be provided in the ventilation system.

(iii) There should be adequate number of fresh air changes in the irradiation room for removal of Ozone. Ozone monitors should be provided in installations where Ozone concentrations are likely to be significant.

(iv) The ventilation system should exhaust Ozone and maintain a low pressure (negative pressure) in the irradiator room to prevent the leak of Ozone to occupied areas.

(v) The discharge point of the duct (stack outlet) of exhaust fans should be located at a height so determined as to achieve dilution of Ozone and other toxic gases below the level prescribed under the Air (Prevention and Control of Pollution) Rules, 1982 or its current version.

(vi) Time delay interlock should be provided to prevent personnel entry into the radiation processing room immediately after the beam is switched off. The delay time should be adequate to allow dissociation of ozone and bring down its concentration below permissible limit of exposure of 0.1 ppm.

(vii) Plant ventilation system should consist of ventilation dampers to stop and isolate air-circulation in an area affected by fire. This should stop spread of smoke and toxic fumes

to other occupied areas, which should be subsequently scavenged in a controlled manner after extinguishing the fire.

4. OPERATIONAL SAFETY

4.1 General

Radiation safety can be achieved by engineering design, administrative control and operational control. In IARPF, design safety plays a major role in ensuring radiation safety. For operational safety, qualified and trained manpower, proper operating procedure and its compliance and necessary infrastructure are important.

4.2 Manpower Requirement

No person under the age of 18 years should be employed as a radiation worker. While employing the workers, the employer[1] should ensure that the workers have appropriate training and instructions in radiation safety, in addition to the qualification and training required for performing their intended tasks as prescribed by the relevant agency. The licensee should designate a Radiological Safety Officer (RSO) for the facility with the approval of AERB. Employees, who are likely to receive an effective dose in excess of three -tenths of the average annual dose limits prescribed by the competent authority should be designated as classified workers. Such employees should be informed that they have been so designated. Every worker, initially on employment, and classified worker, thereafter at-least once in three years as long as the individual is employed, shall be subjected to general medical examination and health surveillance as specified by AERB.

Trained and certified personnel play an important role in achieving operational safety. An IARPF should be operated with adequate number of radiation professionals (certified operators) in every operational shift, and an RSO. The number of staff members and their qualifications should be in compliance with the requirements prescribed by the relevant authority specific to each practice. However, in absence of such prescribed requirements by relevant authority, the suggested provisions are given in this guide. The qualification of radiation professionals for IARPF facility is given in Appendix-III.

4.2.1 Radiological Safety Officer (RSO)

For each licensed IARPF, at least one Radiological Safety Officer (RSO) should be available to ensure compliance with the requirements specified in the AERB Safety code on ‘Radiation sources, equipment and installations’ AERB/ RF/SC, 2025. Where the number of RSOs in a

[1] Typically employer is the Licence holder

facility exceeds one, the designated RSO should be in overall charge of the radiation safety functions and responsibilities as envisaged in Additional Annexure-2.

4.2.2 Operator

(i) There should be at least one trained operator per shift for each radiation generating equipment.

(ii) The operator should be trained by the manufacturer/supplier in operation of the radiation generating equipment.

4.3 Trainee

Students/ apprentice below 16 years of age should not be taken for training in an IARPF. The trainees should work under the supervision of the RSO of the IARPF. The trainees should be subject to personnel monitoring. It should be ensured that the radiation dose to trainees/apprentice of 16-18 years of age should not exceed 6 mSv/year. Dose limits for trainees and apprentices of above 18 years are same as those for occupational workers.

4.4 Monitoring, Protection and Safety Tools/accessories

Operational safety may be effectively achieved by adherence to radiation protection procedures, monitoring of personnel involved in radiation work and workplace monitoring. Personnel monitoring is a combination of individual monitoring and workplace monitoring. Workplace monitoring is monitoring using measurements made in the working environment. Usually contrasted with individual monitoring.

4.4.1 Personnel Monitoring

Radiation Professionals (Operators), RSO and maintenance staff who routinely enter controlled areas of IARPF should be subject to individual dose monitoring. It means determination and estimation of dose received by an individual from external and/ or internal radiation, to check compliance with the dose constraints and investigation levels specified by AERB. These individuals should wear personnel monitoring devices (e.g. Thermo luminescent dosimeter-TLD). The frequency of dose evaluation is on quarterly basis. The institution should ensure that the workers use the TLDs properly. TLD badges should be returned at the beginning of every quarter to the TLD service providing agency. TLDs when not in use should be stored in

locations along with control TLD, where they are not likely to get exposed to radiation generated by plant/ equipment.

Dose records should be maintained by the radiation facility. The employer should furnish dose records to each worker in his employment annually and as and when requested by the worker. In addition to TLDs, the facility should be equipped with a few direct reading dosimeters (DRD). The readings of the DRDs should be maintained in a log book.

RSO should ensure proper use of TLD badges. It should be ensured that separate TLD is issued to radiation worker and it should be worn at Chest area. TLD card should be replaced once in three months and should be stored at designated radiation free area when not in use. Detailed instructions for proper use of TLD are given in AERB website *(https://aerb.gov.in/english/aerb-advertisement).*

4.4.2 Personal Protective Equipment

Specific personal protective equipment (PPE) are generally not required in normal operating conditions of IARPF. However, PPE necessary during emergency condition based on emergency preparedness plan and applicable local safety regulations should be available (like face mask, gloves, shoe covers, lab coat).

4.4.3 Radiation Monitoring Instrument

Suitable radiation survey meters (RSM) should be used for area monitoring of the facility. For IARPFs, ionization chamber-based survey meters should be preferred. Radiation survey meter should be capable of measuring the dose-rate in the range of $0.1\mu Svh^{-1}$ to $1\ \mu Svh^{-1}$. It should be maintained in good working condition and used only with valid calibration. Performance check of RSM should be done on daily basis before carrying out radiation survey.

Radiation survey meters are required to conform that:

(i) The accelerator beam is completely OFF without any dark/remnant current, after its shutdown

(ii) The dose rate outside the enclosure is within the permissible limits.

There should be at least two radiation survey meters for the facility. Radiation surveys should be carried out by the RSO at a predetermined frequency and -

whenever some changes in layouts/shielding are made

- whenever called upon to monitor locations before personnel entry
- before and after undertaking maintenance jobs

Fixed area monitors, with pre-set audio alarm, of appropriate range (capable of measuring dose rate as low as 1 $\mu Sv h^{-1}$) should be installed at the Personnel Access Door (PAD).

All monitoring instruments should be maintained in good working condition with valid calibration. Calibration of RSM should be carried out by accredited laboratories (once in two years) or as recommended by the manufacturer of the RSM and immediately after the repair, and a certificate of calibration should be obtained.

4.4.4 Measuring Instrument

The required measuring instruments [e.g., SF_6 leak detector (where applicable), Oxygen deficiency monitor, RF leak detector, etc.] should be available before commissioning the IARPF for carrying out routine safety checks required during operation. These instruments should be maintained in good working condition and used only with valid calibration.

4.4.5 Handling Tools

This section is not applicable for this Guide.

4.4.6 Mobile Shield/L-Bench

This section is not applicable for this Guide.

4.5 Operation of Radiation Equipment/Sources

4.5.1 Accelerator Safety Envelope (ASE)

A Preliminary Safety Analysis Report (PSAR) should be prepared and submitted to the AERB by the employer of the proposed facility while applying for licence. The PSAR should provide the "Safety Basis" for accelerator operations where the Accelerator Safety Envelope (ASE) identifies the critical controls required to limit risks to acceptable levels. The ASE defines the operating conditions, safe boundaries, surveillance requirements, and administrative controls necessary for safe operations.

Although “Defence-in-Depth” controls are important for accelerator safety, only the very high level safety critical items are included in the ASE. These safety aspects are termed "Credited Controls”, which should be simple, measurable, and actionable. Credited controls identified in the ASE are usually divided into three main categories:

(i) passive controls;
(ii) active engineered controls; and
(iii) administrative controls

ASE violations are serious violations and should be immediately reported to the AERB.

(A) Elements of ASE

(i) Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level:

(a) Automatic systems that limit or terminate operations when operating parameters are exceeded;

(b) A typical active engineered control would be the Radiation Safety Interlock System (RSIS) or Personnel Protection System (PPS).

(ii) Administrative controls encompass the human interactions that define safe operations:

(a) Accelerator operating policies and procedures that are followed to ensure safe accelerator operations;

(b) A common administrative credited control is the Accelerator Control Room Operations Staffing levels.

(B) Examples of ASE

Following are examples of ASE:

(i) The passive credited controls include, permanent shielding, movable shielding, penetration shielding, and radiation fencing that surround the beam line enclosures;

(ii) The active credited controls include, personnel safety interlock and machine safety interlock;

(iii) Allowable beam energy and intensity limitations for each segment of the accelerator chain that need to be monitored to stay within the safety basis;

(iv) Procedure for approving accelerator operations;

(v) Minimum qualifications of personnel on shift, operating the accelerators and the other concerned professionals (Appendix III).

4.5.2 Operating Procedures

A copy of the operating and emergency procedures should be prepared and got approved by the institutions' Local Safety Committee (LSC). It should be maintained in the control room. It should address the methods used to prevent radiation exposure at IARPF. It should include at least the following topics:

(i) Startup, Operation and Shutdown procedure

(ii) Location and operation of the interlock system

(iii) Types and use of radiation personnel monitoring equipment

(iv) Handling of product

(v) Procedures for monitoring such as measuring dose rates and ozone concentration.

(vi) The emergency response procedures

(vii) Search and secure procedure

(viii) Safety checks of critical operating parameters as specified in Section 4.7.1.

(A) Search and Secure Procedure

(i) A sequential 'search and secure' procedure should be carried out by the operator, to ensure that nobody is present in the accelerator beam channel and the irradiation room, by activating the safety buttons located therein. Each safety button should also have emergency stop buttons beside it. At the end of search, the access doors should be secured in the closure mode, and accelerator controls are activated into operational standby mode. The search and secure procedure should be completed

in a pre-decided time with a sequence of operation, failing which the search and secure procedure has to be repeated. Search and secure interlock system should be hardwired.

(ii) A standby mode with a dwell time lasting a few minutes should be provided for before starting the operation of the radiation generating equipment such that if the search and secure is not completed before the lapse of the dwell time, 'search and secure' has to be repeated.

(B) Work Area Zoning

Access to the work areas should be regulated by categorising the areas into different zones. Access control gates should be put at inter-zone boundaries where entry of persons authorised is suitably regulated e.g., biometric or magnetic card. Every work area in an IARPF should be categorized into one of the following zones:

(i) Zone- 1: Normal Area of Full Occupancy

These areas should be accessible all the time and irrespective of whether accelerator beam is in OFF, STANDBY or ON mode. These include places such as- corridors and passages, plant process equipment rooms and product loading/ unloading and storage areas. The radiation shielding should be so designed as to ensure that the radiation dose rate in such areas at any time does not exceed 0.5 μSvh^{-1} for full occupancy and 1 μSvh^{-1} for partial occupancy at any time does not exceed.

(ii) Zone-2: Controlled/Restricted Entry Area

These areas are accessible during beam ON mode with appropriate administrative controls in place. Appropriate area monitoring and personnel radiation monitoring should be provided for workers visiting these areas during beam ON mode. In these places, the dose rate during beam 'ON' may exceed 1 μSvh^{-1} but should not exceed 10 μSvh^{-1}.

(iii) Zone-3: Inaccessible Areas

Areas, having high dose rate during beam ON mode should be designed and engineered with safety interlocks and access/ administrative controls to exclude access and/or breach of safety during beam STANDBY/ON mode.

Only persons authorised should be allowed to enter zone-2 and zone-3 areas and when so allowed they should wear appropriate personnel radiation monitoring devices.

4.5.3 Emergency control mechanism

The facility should have manually operable emergency shutdown switches, which immediately shuts off the electrical power supplies to the appropriate accelerator systems and bring it to safe shut down. These switches should be located near the potentially hazardous areas such as radiation room, the maze area and the beam channel. They should be easily reachable in case of an emergency.

In addition to this, one scram button should be available in the control room.

4.6 Source Location and Storage

This is not applicable for this guide.

4.7 Safety Checks, QA and Maintenance

4.7.1 Safety Check

Adequate arrangements should be made to avoid unintended exposure. The periodic checks as specified by the manufacturer should be carried out and records should be maintained. In the event of detecting a defect in the radiation generating equipment, it should not be used till it is repaired and tested.

All safety and warning device should be checked at regular intervals as specified below and the records thereof should be maintained.

To ensure the continued safe operation of the facility, the employer should ensure that all safety functions are regularly tested by setting up a formal programme of maintenance and testing. The following measures are recommended:

(a) Particular attention must be given to regular testing of safety interlock components for correct operation, according to the instructions of the equipment manufacturers. These tests should be carried out by appropriately qualified persons and should be undertaken in the presence of the RSO.

(b) Portable radiation meters should be calibrated before they are first used, after repair and at intervals not exceeding two years or as specified by the manufacturer of monitors. The pre-use test should include a test of the instrument's overload performance, i.e. it should

operate correctly up to the maximum credible dose rate it may encounter. Response/ Performance check portable radiation meter should be carried out before every use.

(c) Periodic examination of the hoist cable and guide cables should be made and the cables should be replaced as required by existing national regulations or at intervals recommended by the manufacturers.

Weekly tests: The following tests should be carried out weekly:

- A check for correct function of the emergency stop button on the control console, the emergency stop device inside the radiation room, the door interlock.
- Attempts should also be made to operate the facility after deliberately violating the approved startup procedure, to ensure that the interlocks and sequential controls are functioning correctly.

Monthly tests: The following additional tests should be carried out separately on a monthly basis:

(a) A test that the radiation room monitor is functioning properly; this is done by exposing the monitor probe to a check source until the alarm sounds.

(b) A check, in accordance with the manufacturer's instructions, of the safety control systems that prevent access to the radiation room when there is more radiation than specified.

(c) A test that the product exit monitor is functioning properly; the test is carried out, with the facility operating, by exposing the monitor probe to a check source until the alarm sounds. The product exit conveyor should stop immediately and the accelerator should be shut-down automatically.

(d) A test of the source exposure mechanism, the ventilation system and similar hardware, which contribute to the safe operation of the facility and its related product positioning mechanism.

(e) A check that all product containers are undamaged and in good condition.

If any of the checks indicate a fault, or if interlocks do not function properly, the facility should not be used until the required repairs are made.

4.7.2 Test for Quality Assurance

The overall safety in operation depends on the quality of the various components and also quality assurance in the procedures. For this licensee should develop quality manual and implement it. Evaluation of quality should be conducted during construction and periodically during operation. Any accessory or component should not be used unless all the relevant test for quality assurance has been satisfactorily performed. Such tests required for key components must be documented and available with the facility. These tests should be repeated periodically and their records maintained in a logbook.

4.7.3 Servicing and Maintenance

In order to maintain reliability of equipment, periodic servicing as prescribed by the manufacturer of the equipment should be done throughout the useful life of the equipment. It should be done by the persons trained and authorized by the supplier/ manufacturer and certified / recognised by the AERB. The manufacturer or supplier is responsible for supply of original spare and accessories as it is very important from radiation safety view point to use original spare and accessories in the IARPF. In case, servicing and maintenance is not provided by manufacturer/supplier, it may be done by an authorised/ certified agency. A programme of scheduled maintenance, servicing and inspection should be documented and followed for all the systems of the facility. This should include:

- Periodic routine checks as stated in paragraph 4.7.1.
- Preventive/Corrective Maintenance
- Emergency/Breakdown Maintenance
- Ensuring availability of adequate spares and consumables.

The maintenance program pertaining to safety systems and other systems of the facility may typically consist of:

(i) **Monitoring:** Monitoring gives immediate indication of the status of the subsystems to the operating personnel and is normally done from the main control room or during periodic tours of the plant and it should be documented. The monitoring programme should be used for reviews carried out to -

a) Demonstrate compliance with ASE.

b) Detect trends indicating system or component degradation.

(ii) **Functional Checks**: These checks should assure that the tested system or component is capable of performing its design function. It may consist of -

a) Injecting a test signal of an appropriate magnitude to give an approximate read out or actuation of the output, or both.

b) Testing the status and reliability of the interlocks, bypasses, and their indicators/annunciations.

c) Initiating the actuating device and observing proper operation.

(iii) **Calibration and response time verification test:** A calibration verification test is intended to check whether a known input to the equipment or system gives the required output as well as to check its linearity and hysteresis. Response time testing should be a requisite for safety systems, to verify that they are within the specified limits. Calibration should encompass the whole channel consisting of sensing element, recording or indicating and/or actuating instrument. The report /log of maintenance, calibration etc. should be made available to AERB, during inspections or as and when called for.

4.7.4 Safety Interlock Bypass

Need may arise to bypass some of safety interlocks during the installation, testing, repairing, servicing, maintenance and commissioning of the radiation generating equipment. The interlocks should not be bypassed intentionally unless it fulfills the following conditions:

(i) Bypass of safety interlock is authorized by licensee in writing prior to bypass and for a specified time period. Licensee should be informed after restoring the interlock/s.

(ii) Prominent notice is pasted at the control console of the radiation generating equipment and at personnel access door.

(iii) Bypass is normalized as soon as the need for the bypass operation no longer exists.

(iv) Administrative measures should be implemented to ensure that during the operation availing by-pass concession, no untoward incident occurs.

(v) Immediately upon completion of the task that necessitated bypassing, the original interlock should be restored.

(vi) Proper interlock bypass /restore register should be available on control console / control room.

4.8 Decommissioning of Radiation Equipment/Facility

Very low activity reference/ calibration sources which are used for checking the working of radiation monitors are present at the facility, such sources, when no longer required, should be disposed-off with the prior permission of and as directed by the AERB.

In an IARPF, the beam energy used is such that induced activation is not envisaged in products irradiated or of machine/conveyor components and hence the issue of disposal of induced activated material does not arise.

When an IARPF machine is discontinued from regular use and to be decommissioned then the key components such as power supply/ electron gun etc. should be disengaged and ultimately the machine should be dismantled such that no unauthorised person will be able to use it for radiation processing. The components of the IARPF should be disposed-of as per the requirements specified by the relevant authorities.

4.9 Safe Transport of Radioactive Material (Not Applicable for IARPF)

5. MEDICAL EXPOSURE (Not Applicable)

In order to maintain consistency amongst all 15 practice specific guides, all the chapters, sections and sub-sections in the 15 practice specific guides, including this safety guide have been maintained same.

The chapter on ‘Medical Exposure’ is kept intentionally blank since the same is not relevant to ‘Industrial Acceleratory Radiation Processing Facilities’.

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6. HANDLING INCIDENTS/EMERGENCY SITUATION

6.1 General

Emergency is non-routine situation or Events that necessitate prompt action to mitigate hazard or adverse consequences for human life, health, property and the environment. Even though, incidents are less severe than accidents, it needs to be handled properly to prevent further radiation risk it causes to equipment or personnel. Accelerator in an IARPF if operated without following access control procedures and bypassing the safety interlocks, then it may endanger the protection and safety of workers and may lead to emergency.

The emergency situations may also take place due to external factors such as flood, earthquake etc.

Incidents are generally deviation from normal operation which does not cause significant damage to plant and personnel because of appropriate design provisions, nor lead to accident conditions. Facility should have written procedures for management of incidents. The procedure should include how incidents are detected and communicated, who is responsible to manage the incident, and what steps are taken to resolve the incident. All the incidents occurring during commissioning and operation are to be recorded and investigated. Investigation should focus on identifying the root cause and possible solution to prevent recurrence.

The frequent recurrence of incident may result in breach of design provisions and which may lead to accidents or emergency situation. The facility should be prepared and equipped to deal with any emergency situation. This is possible only with careful planning to deal with all types of design basis accidents and accidental situations arising out of external, natural or disruptive factors. Some types of industrial accidents like fire can give rise to secondary situations leading to a radiation emergency.

6.2 Emergency Preparedness for Response

The basic obligations, responsibilities and requirements for emergency preparedness and response are established in Atomic Energy (Radiation Protection) Rules, 2004. Guidance on Emergency Preparedness and Response is provided in AERB Safety Guide on 'Management of Emergency arising from radiation sources, equipment and installations', AERB/RF/SG/NRE-2 (under development). Provisions in regard to radiological emergency are given in AERB Safety Code on 'Management of Nuclear and Radiological Emergencies' AERB/NRF/SC/NRE (2022). The emergency response plan is required to be submitted to the AERB prior to the commissioning of the installations. The licensee, in consultation with Radiological Safety Officer, should prepare suitable Emergency Response plan to mitigate the consequences of foreseeable emergency conditions and maintain emergency preparedness. A copy of the plans should be submitted while applying for Design and Construction approval of the installation. Also, any modifications in the emergency plan should be informed to AERB.

Plan should include possible emergency scenarios, infrastructure requirements (tools, equipment, list of response personnel with responsibility, communication details, coordinators, procedures to initiate response and protective actions) and response functions (action plans for pre identified personnel to undertake response and protective actions). The procedures should identify personnel to be contacted, tools to be utilized and safety instructions to be followed. The procedure should be displayed at a conspicuous location. Further, the equipment required for handling emergencies should be well-maintained and placed at identified locations and easily accessible. Emergency exit pathways should be clearly demarcated preferably with luminescent markings and enable personnel to evacuate the area in case of emergency, with least exposure to radiation or other hazardous situations. The emergency exit pathways should be kept free at all times.

In case of high radiation exposure specialised medical attention may be required and competent authorities must be informed immediately and facility management must be aware of whom to contact to secure help.

The licensee should review the emergency plan at appropriate intervals, normally not exceeding 12 months. Emergency plans should always be reviewed following relevant

operational changes and in conjunction with analysis of and lessons learned from accidents in similar facilities or with similar radiation sources.

A list of typical incidents and emergency situations is given in Annexure-1.

6.3 Response to Incidents/Emergencies

The licensee, on the advice of Radiological Safety Officer, should ensure handling of incidents in such a manner that the exposures to the personnel are minimized. Any such incident and the remedial actions taken are informed to AERB.

Response to an emergency consists of initial actions to be taken immediately and follow-up actions to be taken subsequently. Some follow-up actions may be taken up by the manufacturer/supplier of the accelerator depending on the resources necessary to implement the actions. The emergency response plan should, based on postulated scenarios, provide actions for minimizing radiation exposure, regaining control of the situation to restore the facility to its normal conditions, and treating any persons who have been injured or overexposed. Disconnecting the electrical power to an accelerator will reduce or eliminate further radiation hazards. In addition, potential hazards due to any activation products that may be present should be considered, although scope for such activation in IARPF is nil/negligible.

In the event of an accident involving radiation generating equipment, the licensee (employer) is required to;

(i) make every effort to mitigate the consequences,

(ii) comply with the directions of AERB which may be issued to ensure safety including the immediate shutting down of the radiation installation and

The response action should be as per the plan. However, depending upon the situation, the actions may vary. The protection action should be such that it will reduce the risk. Examples of response actions to be implemented in the case of any incident are given in Annexure-1.

6.3.1 Emergency Handling Tools

The following emergency handling tools (working and calibrated, if applicable) should be available with the institution for handling any radiological incident / emergency in an IARPF

(i) Appropriate and functioning survey meters to measure dose rates;
(ii) Personal alarm and direct reading dosimeters (preferably electronic);
(iii) Emergency light (Torches)
(iv) Communication equipment (e.g., mobile phones);
(v) Spare batteries for survey meters, personal electronic dosimeters and torches;
(vi) Suitable stationery supplies, including an incident logbook;
(vii) Equipment manuals;
(viii) First aid equipment;
(ix) A copy of the emergency procedures.

Emergency equipment should be kept in a clearly labelled cabinet in a readily accessible place. A list of the emergency equipment should be affixed to the cabinet. Audits should be made periodically and immediately after use of the equipment to ensure that all items are present and functioning correctly, or that they are replaced as necessary. Emergency exercise should be conducted periodically. Deficiencies observed during exercise should be documented and promptly rectified. The emergency plan should be revised/ updated accordingly.

6.3.2 Reporting an Emergency

The licensee is responsible for liaison with emergency authorities and other bodies. AERB should be kept informed of any emergency situations, unusual occurrences and occurrences which may have radiation safety implications. Specialized medical attention may be required in case of estimated acute exposure to radiation in excess of 500 mGy and AERB must be informed immediately.

The licensee (employer) should inform the AERB about the incident within 24 hours of its occurrence and submit a detailed report on the incident after carrying out investigations

in consultation with RSO.

After the termination of the emergency, a report should be prepared by the licensee in consultation with the RSO, including a critical review of how well the procedures were implemented, what lessons can be learned and what measures have to be implemented to prevent similar emergencies and incidents in the future and how response plans might be improved.

7. PUBLIC SAFETY

7.1 General

The AERB has prescribed dose limits for members of the public which is given in Appendix-I. To ensure public safety, the design and operation of the facility should be such that radiation exposure to the members of the public is kept at a minimum and well within the prescribed limits. To further strengthen public safety suitable precautionary /security procedures and display of warning symbols should be employed to alert/prevent public before coming closer to hazardous areas of the facility. These efforts should be supported by carrying out regular radiation surveillance around the facility.

7.2 Measures for Public Safety

The Radiation Protection Programme as prescribed by AERB should be established by the licensee, in consultation with RSO, should include the safety of the general public. Graded safety requirements should be established in the facility as per the level of radiation hazards expected to be encountered. Access to the facility by the general public should be controlled in accordance with the zoning arrangement or classification of area (e.g. controlled area/supervised area). To ensure public safety, members of the public should not be allowed beyond Zone/area designated for them. Access control system should be available to ensure entry of only persons authorised to higher radiation zones. In addition, the entrance door of the PARF should be displayed with a radiation warning symbol, which is recognized as "danger" by any member of the public. Regular radiation surveillance should be carried out to ensure that the dose rates in public access areas are acceptably low. Appropriate records of the work place monitoring / radiation survey should be maintained. The radiation exposure of the public from all sources including that due to operation of the facility in one week should not exceed 20µSv considering an annual dose limit of 1 mSv.

7.3 Protection of Fetus

A female worker, on becoming aware that she is pregnant, should notify the employer, licensee and Radiological Safety Officer so that her working conditions may be modified suitably, to ensure that the dose to the foetus remains well within the dose limit prescribed for general public.

There is no additional requirement for lactating radiation worker in the facility as there are remote chances of internal contamination.

Appendix-I Dose Limits for Exposures from Ionising Radiations for workers and the members of the public

AERB DIRECTIVE NO. 01/2011

[Under Rule 15 of the Atomic Energy (Radiation Protection) Rules 2004]

Ref. No.CH/AERB/ITSD/125/2011/1507 dated April 27, 2011

In exercise of rule 15 of the Atomic Energy (Radiation Protection) Rules, 2004, the Chairman, AERB, being the regulatory body under the said rules, hereby issues an order prescribing the dose limits for exposures from ionising radiations for workers and the members of the public, which shall be adhered to.

Dose Limits

General

- The limits on effective dose apply to the sum of effective doses from external as well as internal sources. The limits exclude the exposures due to natural background radiation and medical exposures.
- Calendar year shall be used for all prescribed dose limits.

Occupational Dose Limits

Occupational Workers

The occupational exposures of any worker shall be so controlled that the following limits are not exceeded:

- an effective dose of 20 mSv/yr averaged over five consecutive years (calculated on a sliding scale of five years);
- an effective dose of 30 mSv in any year;
- equivalent dose to the lens of the eye of 150 mSv in a year;
- an equivalent dose to the extremities (hands and feet) of 500 mSv in a year and
- an equivalent dose to the skin of 500 mSv in a year;

Limits given above apply to female workers also. However, once pregnancy is declared the equivalent dose limit to embryo/fetus shall be 1 mSv for the remainder of the pregnancy.

Apprentices and Trainees

The occupational exposure of apprentices and trainees between 16 and 18 years of age shall be so controlled that the following limits are not exceeded:

- an effective dose of 6 mSv in a year;
- an equivalent dose to the lens of the eye of 50 mSv in a year;
- an equivalent dose to the extremities (hands and feet) of 150 mSv in a year and
- an equivalent dose to the skin of 150 mSv in a year.

Dose limits for trainees and apprentices of above 18 years, same as those for occupational worker

Dose Limits for Members of the Public

The estimated average doses to the relevant members of the public shall not exceed the following limits:

- an effective dose of 1 mSv in a year;
- an equivalent dose to the lens of the eye of 15 mSv in a year; and an equivalent dose to the skin of 50 mSv in a year.

Appendix-II Specifications for Radiation Symbol and Warning Sign

AERB DIRECTIVE NO. 02/2011

[Under Rule 14(3) of the Atomic Energy (Radiation Protection) Rules 2004]

Ref.No. CH/AERB/ITSD/125/2011/1508 dated April 27, 2011

In exercise of rule 14(3) of the Atomic Energy (Radiation Protection) Rules, 2004, the Chairman, AERB, being the regulatory body under the said rules, hereby issues an order prescribing the specifications for the radiation symbol and warning sign.

Specifications for radiation symbol/warning sign:

- The radiation symbol for radioactive sources other than medical diagnostic and industrial x-ray radiography equipment shall confirm to the specifications given hereunder;
  - The relative dimensions of the trefoils and the central circle shall be as shown in Fig.1.
  - The trefoils and the circle shall be of magenta colour.
  - The background of the above symbol shall be yellow.
  - The symbol should be accompanied by appropriate legend in English, Hindi and local language indicating radiation hazard and restricted entry, e.g. CAUTION – RADIOACTIVITY.
  - Small objects, containing radioactive material may, however, have on them only the aforesaid trefoil symbol engraved in a conspicuous colour when their dimensions do not permit compliance with the above.
- The radiation symbol for radiation generating equipment such as medical diagnostic x-ray equipment, industrial x-ray radiography equipment and accelerators shall have a warning sign as illustrated in Fig.2 and the warning sign shall conform to the specifications given hereunder;
- The equilateral triangle radiation symbol with ‘CAUTION-X-RAY’ as the warning sign should be used for X-ray sources.
- The ratio of the outer to the inner sides of the triangle shall be 1.5.
- The area between the outer and inner triangle shall be in yellow colour on white background.
- The printing on the area between the outer and inner triangle and figure inside the inner triangle shall be bold, proportional and red in colour.

- The area between the outer and inner triangle should be accompanied by appropriate legend in English, Hindi and local language indicating radiation hazard and restricted entry.

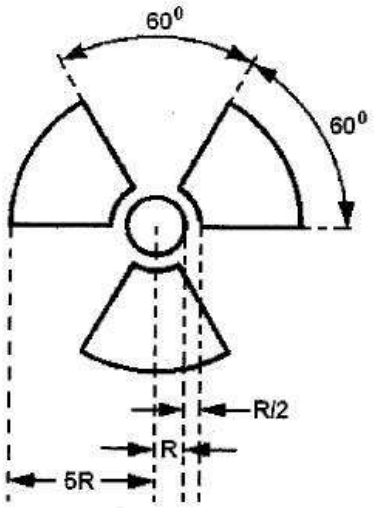

Fig. 1.
Radiation Symbol for Radioactive Sources

Fig. 2.
Radiation Symbol and Warning Sign for Radiation Generating Equipments

Appendix-III

QUALIFICATION OF RADIATION PROFESSIONAL

The qualifications of professionals are stipulated/ prescribed by the relevant authorities. Where such stipulations are not available, the qualifications suggested below may be considered.

1. Radiological Safety Officer (RSO)

1.1 Minimum Qualification:

(i) Basic degree in science with physics as one of the subjects from a recognized University/Institution;

Or;

Degree in engineering from recognized University/Institution;

Or;

Certified operator with diploma having minimum of three years' experience in field of radiation surveillance supported by personnel monitoring service in a radiation processing facility.

Or;

Post-graduate diploma/ degree in Radiological Physics leading to RSO (Industry & Research) certification from a recognized University/Institution;

1.2 Radiological Safety Certification

(i) Successful completion of Radiological Safety Certification (i.e. RSO- Radiation Processing Facilities (RSO-RPF)), from AERB recognized agency.

Candidates who have/possess the required eligibility to be nominated as RSO (Industry & Research) need not undergo additional radiologcial safety certification.

1.3 Licensing/ Approval and Renewal:

(i) Designated RSO should register as radiation professional (RP) with AERB, based on either successful completion of radiological safety certification or possession of approved eligibility;

(ii) Obtain an approval from Competent Authority to function as Radiological Safety Officer (RSO).

(iii) The RP registration and RSO approval is valid for a fixed period as stipulated by AERB, and the same should be renewed prior to expiry of validity period.

2.0 Operator (RPF)

2.1 Minimum Qualification:

(i) Basic degree in Science or equivalent from a recognized University/Institution;

Or

Diploma in Engineering from a recognized University/Institution;

2.2 Radiological Safety Certification

(i) Successful completion of Radiological Safety Certification for Operator of Radiation Processing Facilities (Operator-RPF), from AERB accredited agency.

2.3 Approval /Licensing and Renewal

(i) Certified operator should register as radiation professional (RP) with AERB, based on successful completion of Radiological Safety Certification (Operator-RPF);

(ii) The RP registration is valid for a fixed period as stipulated by AERB, and the same should be renewed prior to expiry of validity period.

Appendix-IV

EXAMPLES OF SAFETY INTERLOCKS TO BE INCORPORATED IN THE DESIGN AND INSTALLATION OF IARPF

Personnel Safety Interlocks	**Machine Safety System and Interlock**
1. Search & secure systems	1. Accelerating structure vacuum interlock
2. Emergency switches and pull rope/ trip wire	2. Cooling water flow interlocks
3. Door interlock	3. Cooling water temperature interlocks
4. Door closure time-delay Interlock	4. Microwave system interlocks
5. Pressure plate/ Intrusion detection system at product entry	5. Waveguide pressure interlock
6. Service Keys	6. Klystron vacuum ion pump interlock
5. Exhaust blower ON interlock	7. Scanning magnet minimum current
6. Air flow interlock	8. Interlock for over voltage/current in power supplies
7. Machine ON status interlock	9. Beam dump temperature interlock
8. High radiation in accelerator vault (to activate the main door solenoid)	10. Collimator ON/OFF interlock
9. Surveillance and PA System	11. Product jam interlock/ Conveyor system
10. Audio visual warning system	
11. Ozone extraction system	
12. Fire detection, alarm and fire-fighting system	

Appendix-V- RESPONSIBILITIES

V.1 General

There are various stakeholders involved in handling the radiation equipment in the complete life cycle of the radiation facility. This includes personnel involved in the manufacture, supply, installation, commissioning, operation, maintenance, and decommissioning of the radiation equipment and/ or radiation facility. Responsibilities are assigned to these personnel for radiation safety in the facility. All the personnel should understand and fulfill their responsibilities to ensure radiation safety effectively. The responsibilities of the employer, licensee, RSO, radiation worker, manufacturer and suppliers of industrial accelerator for radiation processing are provided in this Annexure.

V.2 Responsibilities of Licensee (Employer)

The person responsible for any facility or activity that gives rise to radiation risks should have the prime responsibility for safety. The prime responsibility of ensuring radiation safety during operation of industrial accelerator for radiation processing should rest with the licensee (Employer) who has obtained the licence and this responsibility cannot be delegated.

The licensee and the employer should:

a) ensure compliance with all the applicable provisions of Atomic Energy Act, 1962 and rules made thereunder, and stipulated requirements in regulatory documents/ conditions referred to or contained in the licences or Safety Directives/Orders from AERB or otherwise applicable;

b) designate, with the approval of the AERB, a person having qualifications as specified in this guide, as Radiological Safety Officer (RSO).

c) ensure that person operating the IARPF facility should abide by the provisions notifications/ directives, the relevant Safety Code(s) and their further elaboration in the various safety guides, issued by the competent authority from time to time. Further, ensure that other measures of radiation safety stipulated by the competent authority are promptly implemented.

d) ensure that relevant provisions of this Guide are implemented by the RSO and other worker(s);

e) in consultation with the Radiological Safety Officer, investigate any case of exposure in excess of the specified investigation level received by individual workers and maintain records of such investigations;

f) inform AERB promptly of the occurrence of actual or suspected radiation exposure of personnel in excess of investigation level (i.e. currently radiation dose in excess of 15 mSv in one monitoring period i.e. 3 months) in prescribed format followed by reports of detailed investigations and follow up actions to prevent recurrence of such incidents;

g) ensure that all applicable requirements of other relevant regulatory authorities are met;

h) obtain prior permission of the AERB in case of transfer of ownership of IARPF unit is necessary; and

i) obtain prior approval from the AERB for any modifications in layout of installation.

j) Ensure procurement of only type approved radiation generating equipment

k) in case of permanent termination of the use of machine due to any reason, should decommission the unit with prior permission of the AERB;

l) provide necessary facilities and equipment to the RSO and other worker(s) to carry out their functions effectively in conformity with the regulatory requirements;

m) inform the AERB if the licensee or the RSO leaves employment;

n) Ensure the availability of Quality Assurance Programme during construction of civil structure and records for radiation shielding for uniformity in density and thickness of the radiation shielding is available

o) Ensure that Quality Assurance Testing is carried out for the software used for control and instrumentation system to identify program errors and software bugs, functional testing and performance testing.

p) ensure radiation monitoring is carried out in accordance with this safety guide; ensure adequate radiation monitoring instruments such as area monitors, radiation survey meters and direct reading dosimeter are available;

q) ensure radiation monitoring equipment is/are regularly inspected, maintained and periodically calibrated at least once in two years and all systems/components are regularly serviced and maintained in good working order as per the manual provided by the manufacturer/ designer and records are maintained. Records should also be maintained for replacement of components, if any;

r) ensure periodic tests and inspections of safety systems and control mechanisms are carried out; the records are maintained and are available for inspection by the AERB;

s) ensure that materials which are irradiated in IARPF would not result in hazardous

situations such as fire, explosion and corrosion to arise inside the chamber;

t) ensure that no person under the age of 18 years is employed as a worker and no person under the age of 16 years is taken as trainee/apprentice or employed as an apprentice for radiation work;

u) ensure that adequate instruction/training is given to employees concerning any radiation hazards associated with their work, any precautionary measures necessary to limit radiation exposure of persons and to avoid radiation accidents and injuries;

v) ensure that necessary supervision is provided to all employees in the performance of their work in accordance with the provisions of this guide;

w) ensure that the workers are familiarized with contents of the relevant surveillance procedures, safety standards, safety codes, safety guides and safety manuals issued by the competent authority and emergency response plans;

x) prior to employment of a worker, procure the dose records and health surveillance reports, from his/her former employer. Also, upon termination of service of worker provide his/her dose records and health surveillance reports on request to his/her new employer;

y) arrange for and maintain health surveillance of workers as specified under Rule 24 & 25 of Atomic Energy (Radiation Protection) Rules, 2004;

z) arrange for personnel monitoring of radiation workers, its implementation and also to maintain the individual dose records as prescribed by the AERB;

aa) furnish to each worker dose records and health surveillance reports of the worker in his/her employment annually, as and when requested by the worker and at the termination of service;

bb) ensure that no person is permitted to operate the IARPF equipment/sources unless he/she has been adequately trained and is competent to operate the unit in accordance with the safety procedures

cc) ensure that written procedures and plans are established for controlling, monitoring and assessment of exposure for ensuring adequate protection of workers, members of the public and the environment, during normal operation and emergency situations;

dd) ensure that periodic safety status report of the facility in the prescribed format is submitted to the AERB;

ee) ensure availability of Operation Manual which should include operating procedure for start-up, operation and shut-down of machine;

ff) keep the documents/history of IARPF in safe custody;

gg) ensure the maintenance of logbook for operation and maintenance activities in the facility with specific entries for safety related features.

hh) ensure that emergency plan is available for the facility;

V.3 Responsibilities of Radiological Safety Officer

The role and responsibilities of RSO are elaborated as below:

The Radiological Safety Officer should:

(a) advise and assist the licensee (employer) for the implementation of the relevant provisions of Atomic Energy (Radiation Protection) Rules, 2004;

(b) advise and assist the licensee in ensuring regulatory compliance for obtaining consent from the competent authority;

(c) advise licensee in establishing and maintaining an effective radiation protection programme to ensure safety of workers, members of the public and the environment;

(d) advise and assist the licensee in providing training to the radiation workers on basic radiation safety, hazard potential and biological effects of radiation;

(e) advise employer on implementation of physical protection measures;

(f) advise the licensee on the modification in the working condition of female worker after her notification about pregnancy; and

(g) assist licensee for periodic servicing and preventive maintenance of the unit as prescribed by manufacturer/supplier and maintain records;

(h) assist licensee in maintaining personnel monitoring records, analyse personnel exposure records to ensure that there are no abnormal exposure trends;

(i) assist the licensee in developing suitable emergency response plans to deal with emergencies and ensuring appropriate emergency preparedness;

(j) assist licensee to maintain inventory of (check) sources including initial and present activity, operational logbook and associated QA records;

(k) assist licensee in maintaining personnel monitoring records, analyse personnel exposure records to ensure that there are no abnormal exposure trends;

(l) implement all radiation surveillance measures including display of radiation symbol and warning at the entrance door of the room where the unit is installed and at appropriate location;

(m) supervise that personnel monitoring devices issued to radiation workers in the facility, as applicable, are used as required and are securely stored in radiation-free zone;

(n) ensure that radiation monitoring instruments are kept in working condition and are periodically calibrated;

(o) ensure that radiation monitoring instruments are kept in proper working condition and are periodically calibrated;

(p) conduct daily radiation protection surveys and maintain records;

(q) investigate any situation that could lead to potential exposures and submit report to the AERB through Lcensee;

(r) furnish to the licensee the necessary particulars for the submission of the periodic reports on safety status of the IARPF to the AERB;

(s) report on all hazardous situations along with details of any immediate remedial actions taken made available to the employer and licensee for reporting to the Competent Authority;

(t) inform the competent authority when he/she leaves the RSO position or employment.

(u) instruct all operators other radiation workers on relevant safety measures, provide adequate training in radiation protection and safety methodologies, use of personnel monitoring devices (e.g. TLD badges);

V.4 Responsibilities of Workers (operator/other radiation worker)

Worker (operator/ other radiation worker of IARPF) is the person who is directly involved in day-to-day operation/use of the unit. The worker has recognized rights and duties in achieving radiation safety while handling the radiation source, which envisages awareness about the operational as well as safety requirements of the unit. Accordingly, the workers should get training in safe operation, preventive maintenance aspects of the unit from authorized manufacturer/supplier during installation of the unit at the site.

The worker (operator/ other radiation worker) of IARPF should:

(a) be familiar with the basic design, operation and preventive maintenance of the IARPF including procedures for routine operation and handling emergency situations;

(b) operate the IARPF facility as per the approved Operation Manual prepared by RSO based on detailed instruction manual provided by manufacturer/supplier of the IARPF

unit;

(c) follow all applicable rules and regulations for safe operation of unit;

(d) maintain the logbook in respect of use and operation of the unit including personnel details, products irradiated, dose rate, dose delivered and time of irradiation;

(e) make proper use of protective equipment, radiation monitors and personnel monitoring devices as provided;

(f) report to RSO/licensee of any issues related to safe operation of the IARPF unit, including the circumstances that could adversely affect safe operation of the unit;

(g) be familiar with area security measures such as locks, posting signs, warning lights and interlock systems; and

(h) in case of a female worker, on becoming aware that she is pregnant, notify the employer, licencee and RSO in order that her working conditions may be modified, if necessary.

V.5 Responsibilities of Manufacturer and Supplier

The manufacturer/supplier should:

(a) ensure that only Type Approved IARPF units are supplied and the terms and conditions of the Type approval are complied with;

(b) Indigenous manufacturer should obtain prior licence for commercial production of radiation generating equipment.

(c) Supply new model of imported equipment only after obtaining the requisite NOC for import and supply from the AERB.

(d) supply the unit only to the users authorized by AERB;

(e) install the unit only at premises authorized/approved by the AERB;

(f) provide to the user instruction manual for safe operation, periodic inspection, servicing, preventive maintenance including general description of the unit and detailed operating instructions and procedures;

(g) adhere to the Terms and Conditions of the licence issued for manufacturing and supply of the equipment/sources.

(h) provide appropriate training to the personnel of user institution involved in operation, servicing and maintenance of irradiation unit.

(i) provide to the user, Original Equipment Manufacturer (OEM) issued instruction manual in understandable language (English/Hindi/local language) for safe operation and

periodic testing, including general description of the unit and detailed operating instructions and procedures;

(j) ensure the availability of essential spare parts of the unit for its useful life;

(k) provide servicing and maintenance of the unit whenever required;

(l) provide written instructions to the user specifying procedures to be followed in an emergency situation that has caused or may cause a radiation hazard to any individual;

(m) undertake the responsibility for providing technical support for commissioning/service /maintenance/quality assurance/ decommissioning of IARPF equipment adhering to manufacturers specification, procedures and adhering to regulatory and radiation safety requirements;

(n) carrying out all repair and maintenance procedures as per the manufacturer' specifications or applicable standards;

(o) Submit periodic report in prescribed format to the AERB and also report any unusual occurrences/incidents occurring in models supplied to any other users worldwide.

(p) Ensure that incident reports pertaining to the equipment/sources are made available to the relevant user institutions in the country and corrective actions required, if any, are implemented in the supplied units in the country.

(q) assist the user for handling radiological emergencies in case any such emergency arises because of use of the radiography equipment/devices/source changers;

Annexure-1

EXAMPLES OF EMERGENCY SITUATIONS AND INCIDENTS

Accidental exposure of workers to collimated radiation beams from electron accelerators has led to partial exposure of the body, resulting in severe injuries that may even require amputation of limbs. Such instances are rare. Some accidents which took place in the past are described in A.1.3.

A1.1 Emergency Scenarios

Some of the typical examples of emergency scenarios which need to be considered for preparing emergency action plan in IARPF facility are given below:

(i) Malfunction or deliberate defeat of the safety interlock system and access control systems;
(ii) Inadvertent failure of access door interlock (in tripping the beam) and accidental radiation exposure.
(iii) Failure of radiation generation to terminate even after the intended period of exposure.
(iv) An X-ray generator getting unintentionally energized.
(v) Malfunctioning of a safety system or warning system.
(vi) Physical damage that affects the shielding or beam filtration.
(vii) Excessive-Exposure to radiation worker or members of the public due to unsafe work practice (e.g. bypassing the interlocks, exposure to dark current during servicing of the accelerator)
(viii) Person inadvertently trapped in the irradiation room, when the machine is “ON”

A1.2 Incidents

A typical list of incidents which, if not corrected, may lead to emergency situations is given here:

(i) Beam mis-steering from its designated trajectory or inherent boundary can result in increased radiation dose rates in otherwise normal/full-occupancy locations.

(ii) Beam power may inadvertently rise beyond safety envelope limits due to malfunctioning device/software failure that control particle energy and/or beam current.

(iii) Failure of beam scanning system so that either beam window or product burn out may occur.

(iv) Accidental stalling of product conveying system may lead to fire due to local over-heating.

(v) Beam window rupture due to ageing or failure of cooling air/water system.

(vi) Arcing in sputtering ion vacuum pumps (SIP) due to insulation failure or air ingress - since such pumps operate unattended and in the normally inaccessible areas, cable or power supplies may be set on fire that may spread.

(vii) Insulation cover gas in vessel may undergo overpressure or waveguides arcing at low pressure may lead to gas leakages or damage of safety devices.

(viii) Inadvertent failure of access door interlock (in tripping the beam) and accidental radiation exposure.

(ix) Fire due to any reason in cables, power supplies or product box storage area.

(x) Inadvertent entrapment of personnel in high radiation beam area while switching on beam is imminent or already effected.

(xi) Ozone and noxious gas diffusion into occupancy areas due to high concentration or ventilation failure.

(xii) Abrupt facility black out due to electrical power failure and without power back up coming on.

(xiii) Corrupt operating software or freezing of controls, before/during steady beam operation.

(xiv) Natural calamity events like flooding, earthquake and cyclone/Tsunami (if applicable). Prolonged loss of electrical power.

(xv) Jamming of automatic conveyor systems

(xvi) Fire or explosion inside the irradiation room

(xvii) Failure of access control features

(xviii) Malfunctions and failures of structures, systems and components

(xix) Electrical distribution faults, from localized faults to complete loss of external energy sources

(xx) Failures of safety systems caused by fires within the facility

(xxi) Failures of safety systems resulting from external causes such as storms, floods,

earthquakes or explosions

(xxii) Failures of personnel to observe proper, safe procedures

(xxiii) Breakdown of procedures for preventing access to the facility by unauthorized persons

(xxiv) Breakdown of administrative procedures, leading to unsafe practices

(xxv) High dose rate in locations where high levels are not expected

A1.3 Case Study of Accidents in electron accelerator facilities

Case No.	Cases	Description
1.	Facility	Linear Accelerator with a 10 MeV beam, Illinois (USA)
	Accident	Accident in February 1965 resulting in amputation of leg and arm of one person. Doses of 420- 2400 Gy to various part of the right hand, 2-290 Gy to various parts of the right foot, 2.45 – 3.35 Gy to skin on the right side of the body.
	Initiating Event	The worker entered the irradiation room via a gap under the door, i.e. without tripping the interlock, during the irradiation.
	Contributing/ Causative Factor	The gap under the door enabled violation of operator's procedure
	Responsibility	▪ The operator did not follow the rules to be used when entering the irradiation room. ▪ The gap under the door used to accommodate the conveyor belt was not closed i.e. the licensee was responsible for this error.
	Lessons	▪ The designs of the facility should not be changed by any modification which can jeopardise safety. ▪ The operators should understand and always follow the safety procedures

Case No.	Cases	Description
2.	Facility	Linear accelerator with a 3 MV potential drop, Maryland (USA), 1991
	Accident	Amputation of four fingers of each hand of a worker due to radiation exposure resulting from dark current. The estimated dose was upto 55 Gy.
	Initiating Event	A worker entered the facility to check the assembly while the electron source was turned off. The accelerator potential, however was left on the high voltage terminal. The console meter was showing some current which was approximately 50 mA of cold current. The beam scanning electromagnet was still energized, since it is interlocked with the high voltage on the accelerator. Flashing warning signals were ignored because it was common knowledge at the facility that these signals were connected to high voltage, not to a radiation detection device, as required. Entrance gate was unlocked and the padlock was removed previous to the accident.
	Contributing/ Causative Factor	▪ Two interlock photoelectric cell interlock systems, one at entrance gate and one at the exit gate were not operable. ▪ The maintenance worker did not follow the rules
	Responsibility	▪ The maintenance staff did not have enough knowledge to provide maintenance of the accelerator and to understand the importance to follow the procedures ▪ The safety features should be redesigned i.e. the licensee was responsible for this error
	Lessons	▪ The designs of the facility should enable safe maintenance. ▪ The maintenance staff should be trained to follow rules.
3.	Facility	Linear Accelerator with a 2.5 MV, maximum current of 35 mA and maximum dose rate 80,000 Gy/s, Forbach (France), 1991
	Accident	Three workers received localized doses, one severe enough to produce skin lesions.
	Initiating Event	The three part-time workers entered the irradiation rooms using the exit in order to provide maintenance of auxiliary equipment. Exposed to "Dark current"; the accelerator was switched off but the accelerator voltage was still on. Resulted in dose rates up to 0.1 Gy/s. The whole body doses were up to 1 Gy and doses to the skin up to 40 Gy.

	Contributing/ Causative Factor	▪ The second hand facility had equipment which was not designed for such high exposure fields. ▪ The licensee did not have enough knowledge about safety requirement for such facility
	Responsibility	▪ The licensee using second hand facility did not ensure safety measures to be in place due to a lack of understanding ▪ The licensee did not ascertain/ confirm the competence of the workers ▪ The workers did not follow safety procedures
	Lessons	▪ The maintenance of the facility should be in line with safety precautions. In particular, all auxiliary equipment and materials e.g. oils should be resistant to high radiation field ▪ The operators should be trained to follow rules, as two of the workers were classified as workers of "category B", their competence was not confirmed/ checked.

Case No.	**Cases**	**Description**
4.	Facility	Linear accelerator with 800 kV and 100 mA in France
	Accident	Accidental start of accelerator while checking ventilation System when accelerator in start-up mode resulting in radiation dose of 30-35 mSv (estimated)
	Initiating Event	▪ The incident occurred when three workers deliberately locked themselves inside the irradiation room in order to verify the functioning of the ventilation system. To start the ventilation while remaining inside, the "control rounds" procedure was initiated. This procedure consisted of operating (using the key that closes the access door) four locks placed in different positions, in order to verify that no person is present. ▪ The operator, who remained at the command post and who was to set the machine to "control" mode to start the ventilation system, accidentally triggered the device start-up which caused the activation, in standby mode, of the electron source (a heated

		tungsten filament). In this mode, the electron source is hidden by a shield that stops a significant fraction of the radiation and which is activated by the non-conveyance of the belt. ▪ A few minutes later, one of the operators inside the room detected a bluish glimmer (a sign of the presence of electrons) and heard a suspicious noise; he immediately signaled his two colleagues to evacuate the room, which was done in a few seconds. ▪ The operators in this facility were not wearing dosimeter. The levels of the doses received by workers involved was performed by a dosimetric reconstruction of the accident. The effective doses received by each person were evaluated at between 30 and 35 mSv.
	Contributing/ Causative Factor	▪ Safety Procedures were not in place ▪ The persons involved in the accident did not have appropriate retraining
	Responsibility	The licensee did not assure safety features and appropriate retraining of the personnel.
	Lessons	▪ Safety features must be upgraded in line with international standards retraining of personnel should be in place. ▪ Safety procedures should be in place ▪ An audible and visible signal during the start up of the device would allow anyone present to quickly evacuate the room. ▪ A radiation detection system should be installed inside the irradiation room.

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Date of meeting: January 10, 2022, September 29, 2022

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Dates of meeting: **March 22, 2022, October 28, 2022**

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