GUIDELINES NO. AERB/SG/IS-5

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GOVERNMENT OF INDIA

AERB SAFETY GUIDELINES

SAFETY GUIDELINES ON ACCELERATORS

ATOMIC ENERGY REGULATORY BOARD

AERB SAFETY GUIDELINES NO. AERB/SG/IS-5

SAFETY GUIDELINES ON ACCELERATORS

Atomic Energy Regulatory Board
Mumbai-400 094
India

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Price

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CONTENTS

FOREWORD

All activities involving the use of nuclear energy, nuclear radiation and radioactive sources in the country are to be carried out in accordance with the provisions of the Atomic Energy Act, 1962. In pursuance of the objective to ensure safety of members of the public and occupational workers, as well as protection of environment, the Atomic Energy Regulatory Board (AERB) is entrusted with the responsibility of laying down safety standards and framing rules and regulations for such activities. The Board has, therefore, undertaken a programme of developing safety standards, codes of practice and preparation of related guides and manuals for the purpose. These documents cover aspects such as siting, design, construction, operation, quality assurance, decommissioning and regulation of nuclear and radiation facilities.

Codes of practices and safety standards are formulated on the basis of internationally accepted safety criteria for design, construction and operation of specific equipment, systems, structures and components of nuclear and radiation facilities. Safety codes establish the objectives and set minimum requirements that shall be fulfilled to provide adequate assurance for safety. Safety guides elaborate various requirements and furnish approaches for their implementation. Safety manuals deal with specific topics and contain detailed scientific and technical information on the subject. These documents are prepared by experts in the relevant fields and are extensively reviewed by advisory committees of the Board before they are published. The documents are revised, when necessary, in the light of the experience and feedback from users as well as new developments in the field.

A number of such documents for nuclear power plants and other facilities of the nuclear fuel cycle have been published from time to time by the Board. However, the accelerators are a different class of installations with radiations of much wider energies and quality. Therefore, it is felt that the safety aspects in accelerator facilities operated for application of ionizing radiation in the field of industry, agriculture, medicine and research, need to be addressed separately. Accordingly, AERB constituted a committee in August 2003 to prepare a suitable document to strengthen and consolidate the regulatory framework in the field of accelerators.

These safety guidelines set out the basic safety requirements in accelerators and specify the safety systems to be incorporated at the design stage. It also describes operational safety standards for safe operation and maintenance of the facility. It includes guidance on industrial and radiological safety and specifies the factors that are to be considered in designing shielding. It discusses salient responsibilities of AERB and brings out the procedures for regulatory clearance. It specifies the documents to be submitted to AERB at various stages of the development of the facility like siting, construction, commissioning, operation and decommissioning.

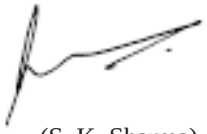
Consistent with the accepted practice, ‘shall’, ‘should’, and ‘may’ are used in the

guidelines to distinguish between a firm requirement, a recommendation and a desirable option, respectively. Appendices are included to provide information that might be helpful to the user. A bibliography of the relevant documents referred to in the text is included. Approaches for implementation, different to those set out in the guidelines may be acceptable, if they provide comparable assurance against undue risk to the health and safety of the occupational workers and the general public and protection of the environment.

Applicable and acceptable national and international standards, codes and guides should be followed in aspects where standards of AERB are not available.

These guidelines have been prepared by a committee comprising of specialists in the field drawn from the Atomic Energy Regulatory Board, Bhabha Atomic Research Centre, Centre for Advanced Technology and Variable Energy Cyclotron Centre.

AERB wishes to thank all individuals and organisations who have prepared and reviewed the document and helped in its finalisation. The list of persons, who have participated in this task, along with their affiliations, is included for information.



(S. K. Sharma)
Chairman, AERB

DEFINITIONS

Accelerator

A device in which charged particles are accelerated. Conventional X-ray tube is not considered as an accelerator.

Activity

The quantity 'A' for an amount of radionuclide in a given energy state at a given time, defined as:

$$A = dN/dt$$

where, dN is the expectation value of the number of spontaneous nuclear transformations from the given energy state in a time interval dt. The SI unit of activity is the reciprocal of second (s^{-1}), termed as Becquerrel (Bq)

ALARA

An acronym for 'As Low As Reasonably Achievable'; A concept meaning that the design and use of sources**,** and the practices associated therewith should be such, as to ensure that exposures are kept as low as reasonably practicable, with economic and social factors taken into account.

Betatron

An electron accelerator in which electrons are accelerated in an increasing magnetic field maintaining a stable orbit of electrons.

Collimator or Field Limiting Diaphragm

A device used for limiting the size and shape of primary radiation beam.

Contamination

The presence of radioactive substances in or on a material or the human body or other places in excess of quantities specified by the competent authority.

Cyclotron

A device in which charged particles (other than electrons) travel in a succession of semi-circular orbits of increasing radii under the influence of a constant magnetic field and are accelerated by traversing a number of times in an electric field produced by a high frequency generator.

Decommissioning

The process by which a nuclear or radiation facility is finally taken out of operation, in

a manner that provides adequate protection to the health and safety of the workers, the public and of the environment.

Dose Limits

The value of the effective dose or the equivalent dose to individuals from controlled practices that shall not be exceeded.

Dosimeter

A device, instrument or system, which can be used to measure or evaluate any quantity related to the determination of either absorbed dose or equivalent dose.

Microtron

A cyclic accelerator in which electrons are guided by a constant magnetic field in circular orbits of increasing radii, tangential to each other and accelerated at the beginning of each orbit, by traversing an electric field produced by a radio frequency generator.

Monitoring

The continuous or periodic measurement of parameters for determination/assessment in respect of structure, system or component in a facility or control of radiation.

Occupational Exposure

All exposures of personnel incurred in the course of their work.

Radiological Safety Officer

Any person who is so designated by the employer and who, in the opinion of the competent authority, is qualified to discharge the functions outlined in the Radiation Protection Rules, 2004.

Synchrotron

Particle accelerators in which charged particles travel in circular orbits of constant radius, guided by an increasing magnetic field and accelerated by traversing a number of times, an electric field produced by a high frequency generator in synchronism with the orbital motion.

1. INTRODUCTION

1.1 General

The Atomic Energy Regulatory Board (AERB) is responsible for ensuring that safety regulations and norms are followed in all operations involving ionizing radiations in the country. In so far as the Department of Atomic Energy installations are concerned, AERB is also responsible for ensuring industrial safety in the operations.

The use of accelerators in various fields is increasing at a rapid rate. Advanced and larger accelerators for research are being designed and commissioned, requiring close regulatory control. The widespread use of accelerators for medical and industrial applications involving import of a variety of machines, which might or might not have adopted the regulatory guidelines, calls for orderly scrutiny. The energy and quality of radiation encountered in accelerators are of a wide range and the control required to make the operations of accelerators safe are also different from those associated with nuclear fuel cycle operations and radioactive sources. These are addressed in these guidelines.

The guidelines have been drawn from the experience of design, erection and operations of accelerators in the various institutions and organisations in the country and will help to meet the safety norms expected by AERB.

1.2 Objective

These Guidelines are intended for all those concerned with design, construction, erection and operation of accelerators in the country. It delineates what is expected of them in meeting the regulatory guidelines and norms. These Guidelines will make them aware what documents are required to be submitted to AERB to seek clearance for siting, construction and authorisation for operation of these machines.

These safety guidelines cover both the radiological and industrial safety aspects, from the stage of design up to commissioning and operation, for achieving total safety of equipment as well as working personnel, the environment and members of the public. Considerations for decommissioning of accelerator facilities are also indicated.

1.3 Scope

Accelerators are devices that accelerate atomic and sub-atomic charged particles to high energies and generate ionizing radiation from the interaction of energetic particles with matter. For the purpose of application of these guidelines, an accelerator is defined as a device employing electrostatic or

electromagnetic fields to impart kinetic energy to atomic or sub-atomic or molecular particles and capable of creating a radiation field external to the device, which is more than 1 μSv/h dose, the limit stipulated by AERB for full occupancy areas. (Ref.1)

The following types of radiation generating machines are excluded from the scope of these guidelines.

(i) Diagnostic X-ray machines

(ii) Any device which accelerates particles to kinetic energy not more than 100 KeV and unmodified devices that do not produce radiation level of more than 1 μSv/h external to the machine.

Examples of such devices are unmodified commercially available units like electron beam welding machines, electron microscopes, high voltage switches, thermo ionic valves, mass spectrometers, spark gap devices, computer monitors and TV screens.

The accelerator facility once authorised for any stage of development, namely siting, design, construction and/or operation, shall remain within the approved configuration or within the safety envelope[1]. If any additions, modifications or upgradation beyond the specifications for which it has been approved are to be effected at any stage, a safety evaluation should be conducted and submitted to AERB to obtain re-authorisation.

Examples of safety envelope are:

(i) Operating specifications for which the facility was approved by AERB.

(ii) The measured radiation intensity produced at the approved maximum operating parameters.

(iii) The safety features and devices associated with the accelerator facility.

(iv) Associated operating and maintenance procedures.

These guidelines describe the facility considerations like siting and layout and covers industrial and radiological safety, radiation shielding, environmental impact and decommissioning aspects. These guidelines cover maintenance and quality assurance programme of the facility and emergency planning. It describes the responsibilities of the operator, user and AERB and specifies the procedures for getting authorisation. It also stipulates the documents that are to be submitted to AERB at various stages of setting up, operation and decommissioning of a facility.

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1 The safe operational limits of a machine that is authorised for the facility and beyond which it may lead to the machine being operated in an unsale condition for the given design.

2. FACILITY CONSIDERATIONS

2.1 Accelerator Types

The extent and depth of safety issues to be addressed depend on the primary particle type, energy and beam[2] power in the accelerator as well as the intended applications of the facility. Accelerators may be categorised on the basis of type of particle accelerated or by the method of particle accelerated or severity of radiation generating potential.

2.1.1 Based on Type of Particle Accelerated

Basic diversity among accelerators exists in the kind of particle accelerated and its energy range. Consequently, accelerators range in size and extent from very compact machines to very large ones.

Depending on most prevalent applications, the charged particles that are accelerated include:

- Electrons (e^-), positrons (e^+), muons etc.
- Light ions; e.g. proton (H^+ or H^-), deuteron, a (He^{++})
- Medium and heavy ions; e.g. C, O, Si, Ni, U

Each particle type accelerated to various energies (expressed in million volts or MeV or MeV/nucleon) has different kind of interactions with matter and poses varying radiation hazards.

2.1.2 Based on Method of Particle Acceleration

Although the basic radiological hazards in accelerator depend on particle type and its maximum energy and beam current, the method used for acceleration has implications on various other kinds of industrial hazards arising out of many different sub-systems involved. A few typical categories of accelerators on this basis include the following:

- HV DC type-using electrostatic fields or voltage multiplier power supplies. Such accelerators are normally limited to terminal voltage up to 25 million electron volts (MeV).
- Radio-frequency acceleration in circular machines-like cyclotron, betatron/microtron, and various synchrotrons.
- Radio-frequency linear acceleration in either drift-tube or waveguide type of acceleration channel.
- Laser based accelerators.

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2 A flow of electromagnetic radiation or particles that is directional and generally collimated, restricted to a small solid angle.

A combination of the above methods of acceleration may be used in large accelerator facilities. Likewise, a facility with a combination of accelerated particles (like electron-proton beam collider[3]) may also be constructed for specific applications.

2.1.3 Based on Severity of Radiation Generating Potential of the Device

Accelerators can be categorised into four classes with increasing severity of the hazards depending upon the beam current, energy and the target[4] involved.

(a) Class-I Accelerator Devices

These devices are incapable of producing an accidental dose >1 mSv in any incident.

Class I devices are designed by the manufacturer to be inherently safe. These devices include shielding and design features that permit operation without requiring significant occupancy controls or personnel in attendance. Very low beam-power electron beam devices, and ion accelerators with particle energy within elastic scattering range may fall under this class.

(b) Class II Accelerator Devices

These devices have potential to produce accidental doses up to three times the occupational annual dose limit in any incident.

Low energy (below photo-neutron emission threshold) and low duty cycle electron accelerators for R&D and ion accelerators (with the exception of deuteron beam) up to about 6 MeV/nucleon may belong to this class, depending upon actual maximal beam power.

(c) Class III Accelerator Devices

These devices have potential to produce an accidental dose in excess of three times the occupational annual dose limit in any incident. Class III devices are unlikely to produce lethal doses of radiation due to the limited area of exposure (i.e., the device configuration excludes the possibility of whole-body exposure from the primary or secondary radiation beams.)

Most self-shielded accelerators except those with significant neutron emission may belong to this category. The device shall have reliable safety interlocks[5] that do not allow operation when any part of self-shielding is removed or altered.

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3 An accelerator in which two opposed beams of particles collide head-on.

4 Target is an object which is placed in the path of a beam to produce a nuclear reaction, secondary beams etc.

5 Interlock comprises an engineered safety system, by activation of which a potentially unsafe condition can be averted.

(d) Class IV Accelerator Devices

These devices have potential to produce an accidental dose more than three times the occupational annual dose limit to the whole body in any incident and may be capable of delivering lethal doses of radiation in case of accidental entry to interlocked beam areas.

Nevertheless, any accelerator type will fall under class-IV when:

- An effective dose rate 1 mSv/h at 30 cm distance from radiation source (after accelerator operations) can be reasonably expected as a result of activation of structures or components, or
- Airborne radioactivity during or after accelerator operations can be reasonably expected as a result of activation of air.

A class-IV accelerator shall be treated under nuclear facility class, where there is possibility of production of mobile radioactive nuclides that must be contained within more than one barrier for preventing their spread into the biosphere and/or causing contamination of plant and animal food chains. Examples of nuclear facility class accelerators include the spallation or photonuclear neutron source facility and radioactive ion beam (RIB) accelerator facility.

The above classification may be used as a general guideline for safety assessment of the accelerator and the requirement as contained in section 9 of this document.

An accelerator facility may consist of a combination of different modules/ segments of above variants. In such case, each of its segments should be evaluated for safety according to its own type.

2.2 Generic Accelerator Configuration

All accelerators can be configured to have all or some of the following main sub systems:

- Accelerating system with electrical input power conversion to high voltage DC and/or to RF power (pulsed and continuous) systems.
- Magnets for guiding or analysing the beam and the associated high current power supplies.
- Accelerating channels with high vacuum systems to enable transport of particles, with minimum loss and maximum gain of kinetic energy, in specially configured geometry of the accelerating device.
- Particle beam emission, steering and focusing elements in beam transport systems using electric and magnetic fields.
- Radiation shielding to protect personnel from the radiation generated by interaction of particles during acceleration, transport and termination or at bending of their trajectory.

- Beam diagnostics and control systems.
- Use of gases like SF_6 for high voltage insulation with potential for industrial hazards.
- Accompanying ventilation system to bring down the concentration of toxic gases, chemicals and airborne radioactivity within permissible levels.
- Cooling systems using water/air for magnets, accelerating cavities, targets and beam dumps.
- Cryogenic systems involving superconducting devices like cavities and magnets.
- Appropriate interlocks and access control systems[6].
- Auxiliary facilities for radioactive material handling, storage, waste storage and disposal etc where applicable.

All these sub systems are to be analysed for safety in operation of the machine.

2.3 Considerations in Siting of Accelerator Facility

The suitability of the site is dependent on the accelerator facility and its design parameters, applications and safety features.

The site for locating an accelerator facility has to be chosen carefully to meet all aspects of operational requirement, safety and impact on the environment under conditions of normal, off-normal operations as well as design basis accidents and situations arising out of natural or disruptive factors.

The details of site characteristics that have to be made available to AERB for seeking regulatory clearance for an accelerator should include:

(1) Location, area, topography, terrain, rocks, soil, rivers, water bodies, ocean in the vicinity

(2) Geological characteristics of the site-floods, storms, rain

(3) Soil survey report with reference to load bearing of the structure, elemental analysis of soil, including lithium activation of the subsoil and ground water wherever applicable.

(4) Seismic data (Seismic zone) of the site. The building and the accelerator design must take into account the seismic condition of the site and seismic design analysis for the facility shall be included in the safety assessment document (SAD) provided to AERB.

(5) Reliability and quality of the electrical power available to the accelerator facility.

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6 Engineered or administrative systems that manage radiation dose to personnel by limiting personnel entry.

(6) Meteorological data on wind speed, wind direction, temperature, rainfall, water logging, flood levels and other factors which might affect the safety aspects in the operation of the accelerator.

(7) Availability of adequate water supply for cooling under all conditions including accidental conditions, and for fire fighting.

(8) Population distribution (demography)

(9) Environmental impact from storage and disposal of radioactive waste generated, if any, in the facility

In addition monitoring of micro meteorological data of the site e.g: windrose, stability class, inversion characteristic, etc, to assess dispersion of radioactive and noxious gases should be initiated. These data should be submitted during 2nd stage of clearance (section 9). A pre operational survey of the background radiation and radioactivity should also be initiated for submission during the 2nd stage of clearance (section 9).

The details of documents that have to be furnished to AERB at various stages, for seeking regulatory clearance for a accelerator are given in section 9

2.4 Layout and Design of the Accelerator Facility Building

For any accelerator facility, the layout and its design criteria must be submitted to AERB along with SAD. Since the building design would include the radiological safety aspects including shielding, disposal/discharge of wastes and airborne radioactive/noxious gaseous products, sky shine[7] etc., the impact of the same on surrounding environment and population must be taken into consideration. The layout design should also take into account the personnel access control details. The structural design criteria, including those for seismic and wind load etc., for the buildings housing the accelerator and auxiliaries, shall conform to those for industrial plant category in relevant national building codes.

In addition, the nuclear facility class accelerator should have a layout, with controls on leakage of radioactive contaminants during normal operation, as well as under reasonably postulated events of accident.

7 Sky shine is the radiation scattered by air molecules after emerging more or less vertically from the shielded enclosure. It causes elevated radiation field outside the shield.

3. SAFETY ASPECTS

The safety aspects envisaged in these guidelines broadly include the following;

- Radiation fields and other hazardous factors in accessible areas are within the relevant regulatory stipulated limits.
- No one remains trapped/present inside the areas with high radiation fields during operation while the primary particle beam is switched on.
- Protection against noxious fumes and gases that may be formed during the accelerator beam operation or in radiation processing of materials.
- An efficient fire protection system is in place.
- Safety against all other conventional and industrial hazards, and non-ionizing radiation which may arise from operation in various sub-systems in the facility.
- Evolving a safety culture amongst operators, users and all personnel working in the facility.

3.1 Radiological Safety Aspects

Accelerated particles incident upon a physical object such as target or walls of enclosing vacuum chamber or components, yield secondary particles and radiations. The yields of these are typically a function of angle of emission and primary energy and beam intensity. In more general case, there is cascade of interactions through the thickness of target. These interactions produce "prompt" radiation[8] in the accelerator which stops when the beam is switched off.

Some interactions, especially those involving neutrons as secondary particles, induce radioactivity through nuclear reactions in the target or surrounding matter. The radiation fields generated as a result of such reactions persist even after the beam is turned off. The prompt radiation as well as induced radioactivity pose radiological hazards, and require protective measures to minimise effects on occupational workers and the public.

Accelerators pose unique problems for radiation safety. The primary particle beam can produce enormous dose rates of radiation over small areas.

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8 Radiation resulting from an accelerator beam or the interaction of the accelerator beam with surrounding matter that ceases promptly after the beam is removed.

Moreover, the secondary radiation (bremsstrahlung[9], neutrons, scattered electrons etc.) can create high dose rates over large areas of the accelerator workplace. In many cases, some of the secondary radiation is quite penetrating. Also, if the primary energy is high enough, residual radioactivity can be produced. Effectively, the net time-averaged primary particle beam power becomes the basic parameter so far as the radiological hazards are concerned.

3.1.1 Objectives for Radiation Safety

The objectives for enforcing radiation safety at the accelerator facility should ensure that:

- During normal operation, maintenance, decommissioning and in emergency situations, the radiation dose to workers as well as members of the public is kept below the relevant dose limits prescribed by AERB (Ref.1). Salient points of Ref.---111 are given in Appendix 1.
- All exposures are kept as low as reasonably achievable (ALARA) and in order to achieve this, the investigational limits of radiation exposure for a quarter, as envisaged in regulatory bodies directives are adopted.

These objectives should be met by maintaining safety features which *inter alia* comprises:

- Appropriate shielding.
- Safety interlocks.
- Access control/effective administrative control.
- Emergency preparedness plan[10] (EPP).

A radiation safety surveillance set up manned by an authorised Radiological Safety Officer (RSO) should be available at the facility to implement the above objectives.

3.1.2 Radiation Shielding (Passive Protection)

The documents submitted to AERB should indicate the details of computation used to design the radiation shield and safety factors adopted. The data on beam losses, on the basis of which radiation source term for the shield design is estimated, should be indicated and substantiated in the design.

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9 Secondary photon radiation produced by deceleration of charged particles passing through matter.

10 A plan to handle any emergency situation that may arise in the installation due to internal or external factors. This is drawn after carefully studying and analysing all possible accident scenarious that are possible. An effective EPP will reduce the effect of occurrence of accidents on the working personnel and the plant.

The shield design shall conform to the dose rate limit of 1 mSv/h in continuously occupied areas as stipulated by AERB. A shield design based on movable shield blocks may be considered only when appropriately engineered to ensure integrity of the structure at all times.

3.1.2.1 Sources of Radiation

The design of shielding requires estimation of the source terms on the basis of the specifications of the accelerator. The most important parameters are: type of particles accelerated and their energy, beam current, target materials and the duty cycle. A realistic and justified beam loss scenario should be considered in arriving at the source term.

To arrive at the source term, contribution from the following should be considered as appropriate to the facility:

- Bremmstrahlung radiation from electron machines
- Characteristic X-rays from interaction of the accelerated particles
- Production of photo-neutrons inside the target and shield due to high-energy photons
- Production of neutrons by the accelerated or secondary beam particles in targets, other accelerator parts and beam dumps
- Prompt gamma radiation from the interaction of ions or neutrons with matter
- Muons and other particles such as pions and kaons may become of concern with much higher primary beam[11] particle energy when these particles are produced.

3.1.2.2 Shielding Design for Accelerators

Unlike the case of nuclear reactors and other nuclear facilities, the radiation source term in accelerators is variable and not homogeneous. This radiation can originate anywhere in the accelerator or beam transport channels. Normally a shield design should be based on loss of total beam at any point.

The designer should assure the regulatory authorities by virtue of margin in design values that the source term will not exceed the values used for design of shielding under any circumstances.

Appropriate beam loss monitors should be installed to prevent the dose rates exceeding the design value. Machine operation should be interlocked with these radiation monitors if required.

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11 Beam of particles accelerated in an accelerator

The following factors are important in shield design:

- The shield designer should take into account the energy of radiation and appropriate flux to dose conversion factors to arrive at the dose equivalent values.
- The occupancy factor for any area for the purpose of design of radiation shield should be taken as 1 (i.e. all areas to be designed for 100% occupancy).
- If due to design considerations shielding thickness in areas is less (e.g. roof), the area shall be made inaccessible during machine operation by suitable interlocking.
- Design of roof shielding should eliminate unacceptable radiation fields due to sky shine in areas far away including public domains around the facility. Though neutron scattering is more than that for photons, photon sky shine should also be considered.
- The estimation of dose rate for design of shielding against radiation scattering via labyrinths, S-bends and ducts, should be carried out, taking into account all possible geometries of the radiation scattering pathways and should be reassessed by actual measurements during initial trial operations.
- Provision for augmentation of shielding, wherever required after the test operation and actual measurement of radiation fields, should be available. In all such cases, the augmented shielding shall form an integral permanent part of the facility layout.
- Accelerator shall be used only to accelerate particles for which it has been authorised to operate, since neutron yield due to low-mass ions could be significantly different.
- Beam catchers[12] and dumps should be carefully designed to stop the scattered radiation. Some beam dumps might require cooling if the intensity of primary radiation falling on it is high.
- At deflectors in the beam transport line etc., there should be adequate shielding to take care of failure of the deflecting fields.
- In some accelerators certain components, like klystrons emitting soft X-ray radiation, need also to be shielded.
- At experimental facilities requiring only a limited fraction of the available beam intensity, it is necessary to design shielding for the full available intensity.

12 A thick shielding to appropriately absorb and stop the radiation beam at the end of its trajectory to prevent unwanted radiation exposures.

- The sources of intense RF radiation used in accelerator facility should be appropriately shielded, taking into account suggested limits of exposure to such radiations (Ref. 2). Salient features given in Appendix 2.
- The materials for shielding have to be selected appropriate to the radiation encountered in the accelerator and its energy. When concrete is used as the shielding material, the likely presence of voids and segregation in casting should be taken care of. In order to overcome this problem, the quality control during construction should be properly documented and followed. For this purpose, radiometric testing of specimen concrete blocks is recommended.
- The water content of concrete is of importance in determining its effectiveness for neutron shielding, particularly in the intermediate energy range. Under some conditions, the water content of concrete may decrease with time. The possible degradation of the shielding due to this should be taken into account in the design. Special low-sodium aggregates may be considered to reduce thermal neutron induced radio-activation of concrete.
- Penetrations in shielding walls (for piping, cables or ductwork) should be plugged using steel or lead wool or small lead pellets (for X-rays and γ-rays); with borax, borated paraffin, or borated plaster (for neutrons). Similarly, any loss of shielding introduced due to the presence of handles in the concrete bricks should be taken care of.

3.1.3 Engineered Protection Systems (Active Protection)

3.1.3.1 Safety Interlocks

One of the key elements of safety in accelerators is the safety interlock system, which should be designed to protect the machine and personnel under any abnormal/unsafe condition. The level of safety provided by this system should be appropriate to the hazards expected from the machine. Beam safety interlocks should be an integral part of the safety interlock system. Beam safety interlocks shall ensure that the primary beam under no condition shall deviate from stipulated trajectory. Interlocks should also ensure that the beam is shut off in case of any potentially unsafe condition. A rigorous program of maintenance to keep the interlocks functional at all times should be in place, introducing desired redundancy wherever necessary. Documents on the safety systems and administrative controls should be made available to AERB for review by experts before implementation.

The choice of the system should be carefully analysed. The systems should be fail-safe against loss of main power, pneumatic device, vacuum, electrical shorts etc. A reliability analysis of the proposed interlocking system should be included in the documents submitted to AERB.

Accelerators are generally modified and upgraded during their lifetime. Care should be taken to include an analysis of how the upgrading or decommissioning of part of the facility will affect the interlocks. If computers are used for implementing the interlock systems then a dedicated computer system is required. If part of the machine is to be decommissioned then such decommissioned parts should not have any influence on the safety of the machine. Cables for safety system should be carefully laid so as not to have impact from fire, RF, EMI. Periodic checking of the interlocks must be included in the facility operations and maintenance procedures.

If any ingress into the beam area is required such as those for product entry and exit then they should be provided with suitable interlocks to shut off the machine in case of accidental personnel entry.

Appropriate documentation on the following aspects should be prepared and maintained.

- Functional description of the interlock systems
- Physical and electrical configuration of the system
- Records of the interlock system tests
- Management approval of the system as it exists

Administrative control should include the following.

- A procedure to review and approve of any changes
- A bypass should be allowed only if it is backed by a work permit[13] or by alternate equipment
- After servicing, the system should be resumed only after suitable tests

3.1.3.2 Access Control System

Depending upon the nature and extent of radiation hazards, an accelerator facility may be categorised into following zones[14] :

- Zone-1: Area which is accessible at all times.
- Zone-2: Controlled/restricted entry area, accessible with appropriate administrative controls.
- Zone-3: Inaccessible area during accelerator operation and controlled entry during shutdown.

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13 A system by which documented clearance is given to peresonnel to carry out an operation involving potentiallyy hazardous work or area and is controlled and supervised by the operator, health physicist and safety officer.

14 A demarcation of the areas in and around the facility, on the basis of the radiation hazard involved, so that personnel movement can be controlled and supervised.

The access control shall guarantee that no one enters the accelerator vault or any other interlocked area in Zone-3, when "No Access Mode" is established. When the interlock logic for a given area is overridden by accident, the access control system should provide a fast turnoff of the beam. Entry into Zone-2 area is controlled effectively both by engineered methods as well as administrative control.

Extent of automation to be incorporated in the access control should depend on the size, nature and hazards associated with the machine. Normally, the Zone-3 category of location such as machine vault or high radiation area, shall be a necessary feature of all accelerator facilities. All entrances to Zone-3 should be interlocked with machine operation.

The logic for the access control should be evolved and submitted to AERB for approval, as certain components of the access control may be dependent on the building layout of the facility. The system designed shall effectively control, regulate and monitor access of personnel to these areas.

3.1.3.3 Search and Secure Procedure

Just before the primary particle beam is switched on, a Search and Secure[15] operation should be conducted in Zone-3 or Zone-2, as the case may be, to ensure that no person has remained in the interlocked areas. The Search and Secure procedure is successfully completed after a series of switches in the form of push buttons are activated in a specific sequence. The buttons must be so placed as to force the operator to proceed to the various locations to ensure that no personnel is left unnoticed. If the right sequence is not satisfied, the system must cancel procedure and demand repetition afresh. The Search and Secure procedure must be completed within a specified period of time.

Scram switches (emergency beam shut-off switches) should be prominently marked to enable an inadvertently trapped person to easily locate them and abort the accelerator start up.

3.1.3.4 Emergency Manual Shutdown

The facility should have manually operated emergency shutdown switches (panic buttons), which immediately shut 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 systems and they should be easily reachable in case of an emergency.

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

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15 The system which forces the operator to carry out a search of an interlocked potentially hazardous area before activating the machine to prevent the posssibility of any personnel getting trapped in the area.

3.1.3.5 Alert and Caution Systems

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:

- An accelerator notification system comprising indicative signs and labels, verbal announcements and warning sounds which inform the personnel on the accelerator operating status, or alert them to potential dangers.
- An appropriate intercom facility with UPS should be available in Zone-3 areas for communication to the control room and other areas.
- Audio-visual warning signal should be annunciated in the Zone-3 area just when the start up of the accelerator particle beam is imminent.
- CC TV cameras should be put at vantage locations for safety as well as surveillance.
- Locations with radiological hazards should be demarcated from other areas by putting appropriate symbols, caution boards etc. indicating radiation levels in work areas and precautions to be taken by working personnel.
- A public address system should be available for announcement of the safety status in the facility.
- Emergency procedures stating what to do in case of emergencies should be posted at all appropriate locations in the facility along with important telephone numbers.
- Emergency lights with appropriate power back up should be provided in all radiation areas, emergency exits and passages, control room and to all Alert and Caution systems so as to enable safety related systems to be active under power breakdown.

3.1.3.6 Administrative Controls and Work Permit System

In addition to built-in engineered safety features the facility should institute suitable administrative control to enforce radiation as well as industrial safety. A work permit system for each specific work duly signed by authorised personnel as well as the Radiological Safety Officer should be in place. A two person 'buddy system' should preferably be adopted in work involving hazardous agents. A display system in the control room indicating the status of the various activities covered by work permits is recommended.

3.1.4 Radiological Protection

3.1.4.1 Organisation

The radiological protection activities shall be supervised by an authorised RSO or health physicist as may be appropriate to the facility. Radiation

protection standards as contained in RPR should be followed (Ref.3). The RSO should be responsible for maintaining a well-documented procedure for monitoring the workers' exposure records and reporting an analysis of exposure to AERB.

3.1.4.2 Personal Dose Monitoring

All radiation workers entering the controlled areas should be covered by personal dosimetry. Before the plant is commissioned, authorised personal dosimetry services should be arranged. In addition, electronic personal dosimetry devices with alarm setting should be available in the facility as appropriate.

The limits of exposure and investigational limits for occupational exposures are given in Radiation Protection Manual (Ref.1) and in the directives of Chairman, AERB (Appendix 1 and 2). All exposures that call for investigation have to be investigated by the facility and the report is to be submitted to AERB. In case of suspected over-exposures the personal dosimetric device should be evaluated immediately. The quarterly reports of personal exposures are to be analysed for trend in changes of the radiation status and important findings should be reported to AERB.

3.1.4.3 Area Radiation Monitoring

The facility should be equipped with appropriate radiation monitoring devices with alarms and these should transmit dose rates to the control desk.

Because of very high energy of photons and neutrons encountered in some accelerators, the facility should ensure that appropriate dose equivalences are established for monitoring purposes.

Radiation surveys should be carried out by RSO or health physicists at pre-determined frequency and in any case:

- whenever some changes in experimental layouts/shielding are made;
- whenever called upon to monitor locations before personnel entry;
- before undertaking maintenance or repair jobs;
- for issuing a work permit;
- radiation monitoring of radiation room and areas after termination of an irradiation before personnel entry.
- In accelerators where there is potential for contamination from activation products, appropriate contamination surveys should be carried out. If required, steps for decontamination should be initiated for which provision should be available in the facility.

3.1.4.4 Monitoring of Visitors

When visitors are permitted by RSO or health physicist to enter the radiation areas they should be escorted by a representative and dosimeters or a representative badge should be provided to the visitors. The RSO or health physicists should brief the visitors on the possible radiological hazards. The visitors should also be briefed on the procedures to be followed in case of any emergency.

3.1.5 Residual Activity

3.1.5.1 General

In accelerators with possibility of neutron production as secondary radiation, activation of various components is a source of radiation hazard. This will be of concern during maintenance, repair and modification. Certain accelerator components like target/collimator and beam-stops etc. used in some accelerators, may have high amount of induced activity. Before carrying out a maintenance job in areas where there is a likelihood of activated components, a detailed radiation survey by the RSO should be made. Internal radiation hazards due to airborne activity or contamination should also be taken into account, if required.

3.1.5.2 Handling, Storage and Disposal of Radioactive Material

When operation of accelerators results in activation of any part, there should be appropriate means and facilities for handling, storage and disposal of the radioactive materials.

Accelerators used for production of radioisotopes (such as for medical applications) involve handling of large amount of radioactivity. Suitable radio-chemistry laboratories with provision for handling, storage and transport of radioactive materials are required. A separate authorisation should be obtained from AERB for operating these laboratories.

All radioactive materials are to be stored/handled only in specially designated areas equipped with facilities to carry out such operations. An inventory of all radioactive materials is to be maintained by the facility and all such sources should be accounted for.

The disposal of radioactive waste from these operations should be made in accordance with the norms set by AERB.

3.1.6 Radiation Damage

The materials used in the machine area are subject to large radiation doses and can undergo degradation resulting in malfunctioning of systems and components. The possibility of such radiation damage has to be carefully

assessed beforehand and program of preventive replacement or using radiation resistant cable and electronic components in critical places should be considered.

In some high-energy accelerators, possibility of radiation damage to structural materials is also to be taken into account.

3.2 Non Radiological Safety Aspects

3.2.1 Industrial Safety and Occupational Health

An accelerator facility apart from being a source of nuclear radiation will involve various industrial types of activities and hence calls for a program of industrial safety. The facility should have an industrial safety program in order to avoid any accident or unsafe situations.

In the Department of Atomic Energy (DAE) units AERB is also responsible to over-see the adherence to the Factories Act, 1948 and the Atomic Energy (Factories) Rules, 1996 and competent persons and safety officers are required to be appointed to carry out tasks and duties as mentioned in the above statutes.

In non-DAE units the responsibility for the regulation of industrial safety is not with AERB, but with state agencies. While obtaining the necessary clearances, the radiation generating nature of the facility must be taken care of. This is due to the fact that any industrial accident may have a bearing on radiation safety.

- First aid provision should be available in the facility along with appropriate staff trained in first aid. A periodic medical examination should be carried out on all concerned workers to ensure that the individual is fit for undertaking his assigned task. A base line medical checkup is required to ensure that the work in the facility does not give rise to any deleterious effects for the person concerned.
- Noise pollution in the work areas shall be monitored and appropriate remedial measures/personal protective equipment[16] (PPE) should be used.
- Appropriate lighting should be provided in the working areas and illumination shall be measured.

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16 Personal protective equipment (PPE) such as respirators, hand gloves, clothing that are used to prevent the intake of hazardous chemical or radioactive material being inhaled, ingested or deposited on personnel.

- Pressure vessels and vacuum systems should be periodically inspected and tested as per specified regulations and should carry necessary certification from a competent person. Preventive maintenance on valves, flanges and piping should be carried out and records maintained. Handling and storage of gas cylinders should be as per gas cylinder rules.
- All hoists, lifts and lifting tackles should be subjected to periodic inspection and testing and should be certified by a competent person.
- All moving machinery should be provided with protective guard.

3.2.2 Fire Safety

Fire fighting capability is one of the key factors to handle fire emergency in a plant and this requires adequate manpower and necessary fire fighting equipment. The facility should have a Fire Order.

Depending on the potential hazards in the plant, suitable fire detection or alarms and fire suppression systems should be installed.

Fire prevention drills and training at regular intervals appropriate to various categories of personnel in the plant should be carried out.

Accelerator facilities under the Department of Atomic Energy shall follow the AERB document “Standard for Fire Protection Systems of Nuclear Facilities” (AERB/S/IRSD-1). Other accelerator facilities should follow the relevant fire safety standards.

Fire exit pathways should be clearly marked preferably with fluorescence indicators and it should be possible to evacuate the personnel working in various locations in case of fire through a quickest and safest path so as not to expose them to additional hazards.

3.2.3 Non Ionizing Radiations and Fields

Radio frequency/microwave radiation is present in many accelerator facilities. Typical primary sources are klystrons, magnetrons, and backward wave oscillators. For most microwave installations, high system performance and safety are mutually reinforcing goals. High magnetic fields are present at many accelerator facilities. While the health risks from magnetic fields are not well understood, there is a particular hazard to persons with pacemakers. High magnetic fields may also present safety hazards from the forces they exert on ferromagnetic materials such as tools. Perceptible or adverse effects have been produced at higher flux densities on persons with other implanted ferromagnetic medical devices (suture staples, aneurism clips, prostheses, etc.). Both magnetic fields and radio frequency fields can interfere with some radiological survey instruments.

The safe limits for personnel protection in the form of Threshold Limit Values (TLVs) for occupational workers are available in literature (Ref. 2).

To avoid exposure of persons to unacceptable levels of RF energy, engineered control measures, such as shielding, prevention of wave guide leakage, enclosures, interlocks preventing accidental energizing of circuits, and dummy load terminations, should be given primary consideration. In addition personal protective equipment (PPE) should be used if required. Where exposure in excess of the limits is possible, RF leakage tests should be conducted when the system is first operated and periodically thereafter.

Appropriate caution boards should be displayed warning of RF and magnetic fields.

3.2.4 Electrical Safety

Electrical safety is an important aspect in accelerators since very high voltages are generated for accelerating the nuclear particles. Where high potentials are involved the devices should be isolated from the working environment by suitable grounded cages. High quality of earthing is a pre-requisite for protection against electric shocks. The electrical grounds as per the safety standards have to be maintained and tested periodically to ensure that the safety features are well in place. To minimise hazards due to high voltage, caution sign boards with danger signs and visual indication should be put up near such locations. Appropriate interlocked doors to the cages should be available so that the high voltage trips if the door is opened before switching off the high voltage. Whenever high voltage generating stations are to be approached for maintenance, use of grounding rods is mandatory, since devices may store significant electrical energy even after switching off the power. Insulated floor matting of good quality should be spread in front of the high voltage units as an additional precaution against electrical shocks.

3.2.5 Ventilation

In facilities (mainly electron accelerators) where possibility of ozone production exists, the ventilation should be designed on the basis of calculated production rate of ozone to reduce its concentration below the permissible level of 0.1 ppm for light work and 0.05 ppm for heavy work. Details of the calculations should be made available to AERB for assessment. Suitable time delay in interlocked doors to such areas should be provided so as to allow personnel entry only after ozone concentration comes down to safe levels after the beam is switched off. The ventilated air must be let off through a stack at a suitable height so as not to allow ground level concentrations above the permissible levels in the surrounding areas, taking into account worst meteorological data for the site. Ozone monitors should be available in facilities where ozone production is possible.

Industrial accelerators may also be a source of noxious fumes and gases evolved during the irradiation process. The ventilation system should also be able to reduce the concentration of such fumes and gases below safe levels before personnel entry.

Similarly ventilation design should also take into consideration formation of gaseous radioactivity such as ^{7}Be, ^{15}O, ^{13}N, ^{41}Ar, if it is expected.

The effectiveness of ventilation designed should be tested using smoke test to ensure that the required number of air changes is available and that no isolated pockets exist in the area.

Accelerators in which SF_6 gas is used for insulation, the storage and transfer areas should have appropriate ventilation and venting. In addition protective gear, such as gas masks for use in case of accidental leakages, should be kept handy. Written procedures for transfers should be available and records should be maintained. Oxygen deficiency monitors should be available to ensure safety of personnel. The storage tanks and piping and gaskets should conform to the relevant safety standards, and should be frequently checked for leakages and preventive maintenance carried out.

3.2.6 Cryogenic Safety

Cryogenic liquids such as liquid helium and nitrogen are used in many accelerator laboratories for cooling superconducting magnets, RF cavities and other devices. Cryogenic liquids present significant hazards because of their intense cold and substantial gas production. The extreme cold not only cause tissue damage to personnel, but can also bring about changes in the properties of metals and other materials. The materials used should have the appropriate physical properties to qualify them for use at these extremely low temperatures.

Asphyxiation and over-pressure hazards are possible by accidental release of cryogenic gas. Care should be taken during storage, transfer and use of cryogenic liquids in order to assure the safety for personnel working with them. Proper ventilation in the areas where there is a possibility of occurrence of asphyxiation should be planned. Oxygen deficiency monitoring should be provided in such areas. The container for cryogenic liquids should have appropriate safety features. Persons handling such liquids should be given adequate training and provided with proper personal protective equipment, appropriate procedures should be documented, followed and proper records maintained. Where applicable, all apparatus used in the storage and handling of cryogenic liquids, should meet the statutory requirements.

3.3 Additional Safety Aspects in Medical Accelerators

Medical accelerators represent a type of machine which involves the presence of a person (patient) in the high beam area during operation. A treatment planning system and other patient safety procedures and devices must be in place as recommended by the competent authority. No facility for medical applications shall be used without the availability of an authorised medical physicist. Quality control of the machine and treatment system is extremely important to ensure that the dose delivered to the patient is specific to the treatment done under medical and radiation physicist supervision.

Facilities such as Positron Emission Tomography (PET) are equipped with machines for producing suitable radioisotopes. Such facilities should have approved suitable radioactive laboratories to handle the radioactive materials. Appropriate facilities for storing and disposing off any radioactive waste should also be considered in setting up such facilities.

Since these facilities are expected to be set up near heavily populated areas and with intense public movement, extreme care should be taken in respect of environmental radioactivity and radiation beyond the control areas.

4. OPERATIONS

It is the responsibility of the licensee to operate the facility in a safe and orderly manner to achieve all safety goals set by the regulatory authority. A high degree of flexibility is generally noticed in the operation of accelerator facilities particularly those used for R&D applications to meet the objective of the experimental programs. So it is particularly important to evolve specific guidelines and appropriate procedures for accelerator operation so as to carry out its objectives in a safe manner, keeping radiation exposures to a minimum, adopting the ALARA principle. The operational sequence to ensure safe operation should be established and documented in the operators' manual. An organisational chart and delineation of the line of responsibility should be available.

The machine should be operated only by qualified and trained personnel authorised by the facility authority. Operator training and authorisation is a key element and a procedure for this has to be evolved in house. Procedures should establish and describe the line of authority and responsibility. All activities in the facility should be coordinated in an orderly fashion according to a line of authority allotting responsibility for each action. Procedures should also define programme goals, availability of resources and interfaces to other groups related to safety, performance monitoring guidelines, accountability, training, awareness of duties and responsibilities, emergency response requirements, log keeping and reporting requirements. The control room shall not be left un-manned during operations and the operator should have control over personnel movement in the restricted and controlled areas. All personnel entering the interlocked areas during maintenance shutdown should be accounted for by the operator as appropriate to the facility. A system of work permits for such operation, with logging of all work being undertaken, should be carefully instituted. The procedure for start up of the machine shall not be initiated unless all the work permits are cleared and all personnel working in interlocked areas exit out. Search and Secure operation is to be taken only as a defence in depth. Appropriate channels of communication should be available for coordinating all activities connected with operation, maintenance, etc in the facility. This could range from simple line of sight from the control room to audio visual electronic communications depending on the complexity of the facility. Guidelines should be established to ensure that research and development programs at the accelerator facility are conducted, consistent with all facility safety requirements. The operator shall be responsible for maintaining a logbook of all activities connected with the accelerator operation, maintenance, repair and modification. There should be administrative control system to ensure that the equipment are properly labeled as appropriate to the facility. The operator must be aware of any modifications that are made in the system during maintenance and evaluate its implication to safety before operating the machine.

If the designer, supplier, erection agencies are diverse, then there shall be continuity

of the responsibility for the safe operation of the facility, which will finally rest with the licensee.

In order to achieve safe operation, the facility should have suitable protection features to guard against following adverse conditions:

- Main power supply instabilities
- Accidental high ambient temperatures
- General elevated operating temperatures
- Over-voltage/Over-current
- Single-phasing
- Short-circuit
- Sudden loss of good quality ground
- Cable fire
- Fire accident
- Mechanical damage
- Loss of coolant
- Water ingress
- Manifestation of rodents and other small creatures which can cause short-circuit
- Sabotage

5. MAINTENANCE

A programme of scheduled maintenance and inspection should be documented and followed for all the sub-systems of the facility. This should include:

- Periodic routine checks
- 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 consists of:

5.1 Monitoring: Monitoring gives immediate indication of the status of the sub-systems 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. This documentation may be in the form of logbooks, computer printouts, log-sheets or recorder charts and preferably electronically recorded. Monitoring documentation should be used as the basis for reviews carried out to

- Demonstrate compliance with operational limits and conditions.
- Detect trends indicating system or component degradation.

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

- Injecting a test signal of an appropriate magnitude to give an approximate read out or actuation of the output, or both.
- Testing the status and reliability of the interlocks, bypasses, and their indicators/annunciations.
- Initiating the actuating device and observing proper operation.

5.3 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 available to AERB during inspections or as and when called for.

6. TRAINING

AERB's directive requires that all persons working in a facility are given safety orientation appropriate to their tasks and responsibilities. All users, operators, maintenance staff and whosoever is required to enter the facility for carrying out any kind of activities are all to be briefed on the radiation safety issues in general and about the plant in particular. In accelerators it is an important element because there is a significant turnover of users and teams of users who may not be very well conversant with the risks of working with nuclear radiation. All of them should be trained in such a manner that does not unduly place them or others at a risk. They should also be briefed on the general layout of the facility and procedures in case of emergency. They should be aware of what to do under such circumstances and whom to contact. It is also appropriate to have clearly laid out handouts available for such users.

Some personnel particularly the operators and maintenance personnel need to be given more detailed training. The training program should include radiation safety training, facility specific safety training and task specific training. A system for recording training results and a mechanism for formally confirming that an individual has been trained to perform his duties in a safe manner should be evolved. The operators should be trained in the operation of the machine and should have a manual for the operation and check lists for each type of assignments. They should be conversant with the work permit system in the facility. The responsibility of all training rests with the management.

The users and other personnel must be aware of the radiological status in the working environment and take care of any changes due to alterations in the experimental set up or in the facility.

In addition training in industrial safety is required for the concerned personnel.

7. QUALITY ASSURANCE

The overall safety in operation depends on the quality assurance of the various components and also quality assurance in the procedures. For bigger machines a probabilistic safety analysis is suggested.

A quality assurance evaluation should be conducted during construction and periodically during operation. Any accessory or component should not be used unless all the relevant quality assurance tests have 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.

The licensee should ensure that a written quality assurance manual is established. The manual should be kept up to date and contain at least the following:

- A copy of the license, conditions if any, and applicable regulations
- Organisation scheme
- Quality Assurance in training programs
- Quality Assurance in radiological protection
- Quality Assurance of equipment used and safety systems handling
- Quality Assurance in shielding
- Surveillance procedure for functional checks at regular intervals, of safety systems, equipment, instruments and radiation monitoring systems
- Surveillance for calibration and check of radiation protection instruments at regular intervals
- Surveillance for transport of radioactive substances
- Routines for yearly inventory of sealed sources
- Quality Assurance for emergency procedures
- Quality Assurance for safety analysis, its documentation and reporting and
- Quality Assurance for internal audit.

8. EMERGENCY RESPONSE PLANNING

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. When an accident occurs, workers and the public may be exposed to radiation hazards or hazards from any industrial agents. Some types of industrial accidents like fire can give rise to secondary situations leading to a radiation emergency. In non-DAE installations though AERB is not responsible for industrial and fire safety, it must be borne in mind that the clearance from the competent regulatory authorities must be obtained and the type of hazards which may have radiation implication have to be kept in view.

Adequate emergency procedures specifying steps to alleviate the damage to personnel and property shall be available with the facility. The responsibility for preparation of suitable documents rests with the facility. The organisational responsibility for each action must be delineated and the required information as to whom to contact etc. must be displayed in the facility. The procedures should also include the name and telephone numbers of the persons to be notified for directing remedial action for example the police fire brigade, medical help, and competent authorities. 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 operating organisation is responsible for liaison with emergency authorities and other bodies. AERB shall be kept informed of any emergency situations, unusual occurrences and occurrences which may have safety implications.

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.

9. REGULATORY CLEARANCES AND DOCUMENTS

In order to enable AERB to evaluate a proposal for siting, construction and operation of an accelerator facility, several documents are required at various stages. AERB can authorise the setting up of a facility only on the basis of the technical information provided to it. There are committees of the regulatory board consisting of qualified experts to go through these documents to evaluate safety and recommend the authorisation. The following Table-1 gives the documents (appropriate to the facility) required by AERB to enable it to carry out the evaluation process. If it is felt that if certain requirements (for a particular facility) are not applicable, due to its type and nature, the same may be indicated in the application. The Board may call for additional information as required to meet its obligations, and the representatives of the applicant may be required to participate in the review meetings, to provide any clarifications. The approval for the accelerator facility layout should be obtained from AERB, before starting of construction. Any upgrade modification that might be required should also be kept in view, while evolving a conceptual design.

Depending on the size and nature of the facility, a stepwise procedure of authorisation starting from the approval of site, layout of the buildings, auxiliary facilities required, construction, trial operation followed by regular operation is envisaged. AERB may give authorisation for trial operation at various stages of beam power.

In respect of imported machines all documents from the supplier should be made available to AERB, to evaluate the permission to import. The safety standards differ from country to country and hence an evaluation of the safety features with respect to AERB's norms need to be carried out. In case of medical therapy machines, a type approval procedure is also involved. In case of a mobile accelerator facility, the information required for stages 1 and 2 should be combined.

TABLE-1: DOCUMENTS REQUIRED FOR EVALUATION PROCESS

Stages of Regulatory Permission	Documents and Information Required for Regulatory Permission
First stage of permission for location and siting of the facility, including import of accelerator device	1. Description of the facility, specifications of the machine with maximum power, operational features of the machine and the maximum inventory of radioactivity involved, and the end use of the facility. 2. Details of proposed site including area map. Meteorological data of the site. Element analysis of the soil of land of site and analysis of the filling materials including analysis of lithium content. A layout diagram of the proposed site, indicating all the units and the distance between them inside the boundary and the vicinity of the site in all directions.* 3. Justification for and evaluation of the particular site for locating the facility. 4. Identification of hazards and probable effects on workers, public and the environment, from normal operation and off-normal and accidental conditions. Means of mitigation of these hazards. Expected radioactive waste generation in solid, liquid and gaseous forms; their handling, effluent treatment and disposal method. 5. Facilities available near the site, to deal with accidental conditions. 6. Details of any existing or planned auxiliary facilities handling radioactive materials/ radiation/industrial toxicants, within the site or located near by. 7. Other supporting documents, if any.

* The details required for site evaluation are explained in section 2.3.

TABLE-1: DOCUMENTS REQUIRED FOR EVALUATION PROCESS (CONTD.)

Second stage for regulatory permission to commence facility construction/ augmentation.	1. Facility details with design manuals including civil engineering layout and the location of the machine. 2. Micro-meteorological data of the site 3. Pre-operational survey report of the background radiation and radioactivity 4. Shielding design drawings and details. 5. Preliminary Safety Analysis report including: (i) Details of safety interlocks and access control systems and zoning (ii) Radiation hazard control setup details 6. Details of ventilation system for removal of noxious gases generated. 7. Radioactive material handling and waste management details, if applicable 8. Analysis of design base or postulated emergency conditions, including those due to natural or disruptive factors. Demonstration of adequacy of protective measures provided in the design. 9. Quality Assurance (QA) programme to be implemented during design and construction of the facility. 10. Supporting documents
Third stage permission for system-wise and/or integrated commissioning of facility and trial operation.	1. Compliance report for the conditions/ mandate specified along with earlier regulatory permissions. 2. Authorisation of AERB for appointment of RSO; Safety organisation set up. 3. Submission of final documentation for the facility: (i) Safety assessment document

TABLE-1: DOCUMENTS REQUIRED FOR EVALUATION PROCESS (CONTD.)

	(ii) Specifications of all systems (iii) Design manual of the facility (iv) Facility layout with details of site and building features. (v) Facility operation manual; procedure for maintenance and re-test (vi) Organisational setup with responsibilities (vii) Internal safety review setup and reporting system (viii) Operator training and authorisation report (ix) Arrangementsfor personal dosimetry and environmental monitoring (x) Training programme for facility-specific safety (xi) Quality assurance manual (xii) Emergency preparedness plan of the facility (xiii) Supporting documents
Final stage for regulatory permission to continue routine operation of the facility	1. Integrated test report of the facility 2. Compliance of all recommendations made and requirements for earlier stages 3. Radiation monitoring report during test runs 4. Analysis of any unusual occurrences during the earlier stages 5. Requests for approval for any modification and upgradation. 6. Internal Safety Review Organisation and periodic reporting procedures to AERB

10. RESPONSIBILITIES

10.1 Safety Personnel

The facility should not be commissioned unless the services of a Radiological Safety Officer (RSO), approved by the competent authority (AERB) are available. The facility licensee must ensure the authorisation of the RSO as required by AERB's directive. The RSO must implement the radiation safety surveillance program of the facility, shall prepare periodic safety reports for transmission to AERB and also ensure that all radiation monitoring and safety equipment are at all times kept calibrated and in working condition ensuring redundancy wherever required. The RSO is responsible for advising the licensee on all matters pertaining to radiation safety in the facility and maintaining of radiation personal exposure records and radiation monitoring reports. The RSO is responsible for:

- Conducting radiation surveys and measurements
- Developing accelerator radiation standards
- Acquiring, distributing, maintaining and calibrating radiation monitoring equipment
- Maintaining radiological protection records
- Supervising shipments of radioactive materials entering or leaving the facility
- Ensuring that appropriate dosimetric methods are available
- Providing interpretation of exposure records and monitoring data
- Advising the management for keeping personal radiation exposures below the limits specified by AERB (Ref.1) and to adopt ALARA principle
- Preparing handouts and safety instructions for the personnel working in the facility
- Organising radiation safety training
- Keeping ready and make available personal protective equipment, as relevant to the facility
- Ensuring that the operation of the facility at no time leads to any radiation impact on the environment, beyond that permitted by AERB.

10.2 Operating Personnel

The facility should be operated only by personnel authorised by the licensee. The operating personnel shall carry out the duties allotted to them by the management as per the operating manual, to achieve the safety goals set by AERB.

10.3 Therapy Team

In case of accelerators for medical applications, a team comprising of radiation therapist, medical physicist and therapy technicians duly trained, shall be available at the facility for patient protection, operational safety and radiation safety of the operational staff and the public.

10.4 Licensee

It is the responsibility of the licensee to ensure that variations in operating conditions may be permitted only if they do not exceed the bounds of the accelerator safety envelope, as pertaining to the specifications for which the license is granted.

The responsibility of ensuring radiation safety, availability of qualified personnel and providing them requisite facilities to discharge their duties and functions, shall rest with the licensee. He shall ensure due compliance with the terms and conditions of the license issued to him by the competent authority. Further, he shall provide all necessary facilities to the RSO to discharge his duties and functions, appoint relevant local safety committees to review the safety performance of the facility and periodically keep AERB informed about the safety status. The licensee is responsible for implementing the recommendations of AERB and should not expect AERB to work out the technical details of the manner of implementation.

The licensee shall make available all records and information to AERB and should facilitate the inspection of the facility whenever required.

The licensee shall keep AERB informed of all accidents, unusual occurrences or events that may have a safety implication, with relevant details.

10.5 Regulatory Body

AERB should review the applications to locate, construct and operate the facility and call for any additional information from the applicant to review the proposal. AERB, if satisfied with the safety aspects of the proposal will issue stage by stage authorisation. AERB may send its representatives to inspect the site, construction and the operation of the facility, from time to time, to review the safety performance. AERB should from time to time review the safety status of the facility. It has the right to impose operational restrictions if any lapses are found. It is advisable that AERB adopts a checklist to ensure that the facility conforms to all the safety recommendations.

10.6 Users

Accelerator facilities generally have a relatively large number of floating workers who use the machine for their experiments, or who bring their products for processing, or patients and relatives who interact with the facility for medical treatment. The users should be conversant with the hazards from the ionizing radiations and radioactive materials. The facility personnel are responsible for briefing the users on the safety requirements and procedures. The users must abide by the instructions given by the facility personnel and cooperate with them to ensure the use of the machines in a safe and friendly manner. The user should obtain clearance from RSO for activities in radiation areas.

11. DECOMMISSIONING ASPECTS

All nuclear installations pose a problem of decommissioning and accelerators are no exception. Depending on the size and nature of the machine the problem posed may vary from simple to complex. Since this aspect is generally lost sight of while designing a facility and when required it becomes impossible or difficult to take cognisance of the safety features, it is imperative that due thought is given to this.

Depending on the nature of the facility there may be activated parts of the machine and structural and shielding materials, which need to be disposed off according to the radioactive waste disposal regulations. Even in the case of other components, provision has to be made to carry out the disposal in an environment friendly manner.

AERB has to be assured that these considerations are taken care of by the licensee before AERB gives approval to set up a facility.

12. INTERNAL SAFETY REVIEW AND OCCURRENCE REPORTING

Safety evaluation of the facility involves a multi-tier safety review by AERB. The facility should have a Radiological Safety Officer or a team of Health Physicists and an Industrial Safety Officer as is appropriate for the facility. The licensee shall appoint a local safety committee, with participation from the operational/maintenance staff, Radiological Safety Officer (RSO) and Industrial Safety Officer as relevant to the facility, to periodically review the safety status, exposures and unusual or off normal occurrences in the facility. This internal safety review system should provide the management reasonable assurance that the safety issues are not being overlooked or ignored. The RSO and local safety committee serve as useful links with AERB to ensure that the safety norms are followed and the facility operated in a safe and proper manner. The local safety committee should meet at least quarterly or soon after an unusual occurrence. The radiological safety status of the facility should be discussed in the local safety committee and records of such meetings should be available with the facility and periodically reported to AERB. Any emergency, accident, off normal occurrence, events that may have a safety implication, or any operational parameters exceeding the safety envelope should be discussed in the local safety committee and the findings reported to AERB within stipulated time, depending on the severity of the event.

APPENDIX 1

सत्यमेव जयते
डॉ. पी. रामा राव
अध्यक्ष
Dr. P. RAMA RAO
CHAIRMAN

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GOVERNMENT OF INDIA
ATOMIC ENERGY REGULATORY BOARD
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INDIA.

No. AERB/CH/SD/99/ 593

February 17, 1999.

AERB Safety Directive No. 7-1999

AERB had issued several Safety Directives from 1991 to implement in a phased manner the recommendations of the International Commission on Radiological Protection (ICRP) on dose limits for radiation workers stated in its Publication no 60. The last Directive was issued in 1994 and covered the five year block starting from January 1, 1994.

The Regulatory Board hereby issues the following Safety Directive prescribing the dose limits for occupational exposures to ionising radiations.

I. Effective Dose Limits

1) The cumulative effective dose limit for each consecutive block of five years starting from January 1, 1999 shall be one hundred millisievert (100mSv) for individual radiation workers.

2) The annual effective dose to individual workers in any calendar year shall not exceed the limit of 30 millisievert (30mSv)

II. Investigation level

Individual effective dose exceeding 20mSv in a year shall continue to be reviewed by the Committee set up by Atomic Energy Regulatory Board.

P. Rama Rao

(P. Rama Rao)

APPENDIX 2

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ATOMIC ENERGY REGULATORY BOARD

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July 22, 1991.

AERB SAFETY DIRECTIVE - 2/91

All future plants/facilities including those under design shall be based on ICRP-60 which recommends that the dose constraint for optimisation should not exceed 20 mSv in a year for occupational exposures and 1 mSv in a year for the public. In compliance with this:

a) The shieldings to be provided shall be such that the dose rates in full occupancy areas do not exceed 1 uSv per hour (0.1 mrem per hour).

b) The ventilation designs shall be such that the air concentration of the activities in full occupancy areas do not normally exceed 1/10 of the new derived air concentrations (DAC). The new DAC values can be obtained by dividing the annual limit on intake (ALI) values given in ICRP-61 by 2.4×10^3.(These ALI values for commonly encountered radionuclides are given on the reverse).

c) All effluent discharges from a plant/facility/practice shall be so controlled that the exposure of the critical group does not exceed the public dose limit of 1 mSv in a year (excluding natural background and medical exposures) from all practices at the site.

SDSoman 22/7/91

(S. D. SOMAN)
Chairman, AERB

APPENDIX 3

CONTENTS OF SAFETY ASSESSMENT DOCUMENT

The purpose of preparing a **Safety Assessment Document** (SAD) is to ensure that the measures taken to minimise the consequences of hazards present in the proposed activity, or to mitigate their consequences, are sufficient to make the risks of the proposed activity acceptable. The contents of the SAD shall include:

1. Introduction

This chapter should provide a basic understanding of the facility function and the protection afforded to the public, workers (health and safety), and the environment.

2. Executive Summary

The summary should provide an overview of the results and conclusions of the analysis contained within the safety assessment. The summary should address the results of Chapter 4 and Chapter 5 of the SAD.

3. Site, Facility and Operations Description

a. This section should describe the accelerator site location and provide specific data for characterising the site.

b. This section should also describe the accelerator by providing design criteria and as-built characteristics for the accelerator, for its supporting systems, and for components with safety-related functions.

c. For new facilities and those to undergo major modifications, a Fire Hazards Analysis is to be included.

d. How the facility fits into the contractor's organisation, is to be described.

e. The experiments which will use the accelerator should be described, including those design criteria and characteristics of the experimental equipment, systems and components, having safety-related functions.

f. An operations/process description of the accelerator facility should be provided. Both potential accident and normal operation conditions for the machine and the experimental program should be appropriately detailed.

g. The design process and SAD should consider the worker safety conditions.

4. Safety Analysis

a. This section should document the accident analysis, including any systematic methodology (i.e., Failure Mode and Effects Analysis, Fault Trees, etc.) used for the identification and mitigation of potential hazards.

b. This section should discuss the methods used at the accelerator facility to control and mitigate the potential hazards.

c. The residual risk to the facility, workers, the public, and the environment should be discussed.

5. Accelerator Safety Envelope

This section should provide the Accelerator Safety Envelope (ref. section 1.3) that will establish and define the limits of operation for the facility/operation.

6. Quality Assurance

This section should describe the quality assurance (QA) program to be applied to the accelerator facility

7. Decommissioning and Decontamination Plan

A description of structural and internal features which would facilitate decommissioning and decontamination of the accelerator complex should be provided in this section. Waste management of radiological and hazardous material generation from the decommissioning and decontamination operation should be discussed.

8. References/Glossary/Abbreviations

In short, the SAD shall contain the following:

- A description of (or a reference to) the facility's function, location, and management organisation, as well as details of major facility components and their operation.
- Hazards from both normal operations and credible accidents in the facility and associated onsite and offsite impacts to workers, the public, and the environment.
- Sufficient descriptive information and analytical results pertaining to specific hazards and risks identified during the safety analysis process, to provide an understanding of the risks presented by the proposed operations.
- A detailed description of engineered controls (e.g., interlocks and physical barriers) and administrative controls (e.g., training)

implemented to eliminate, control, or mitigate risks associated with the operation.

- The set of physical and administrative bounding conditions for safe operations, based on the safety analysis documented in the SAD. These bounding conditions are known as the Accelerator Safety Envelope (ASE). Any activity violating the ASE shall be terminated and immediately notified to AERB.

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LIST OF PARTICIPANTS

COMMITTEE TO PROVIDE SAFETY GUIDE ON ACCELERATORS

Dates of meeting	:	October 14, 2003 January 23 & 24, 2004 March 25 & 26, 2004 June 6 & 7, 2004 January 3 & 4, 2005 (for incorporation of comments from reviewers)

Dr. M. R. Iyer, Former Head, RSSD, BARC	Chairman
Shri. N. K. Mukhopadhyay, Head, AOG, VECC	Member
Shri. P. K. Nema, SO/H, NPD, BARC	Member
Dr. Arvind Jain, Head, AT&CS, APPD, BARC	Member
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PROVISIONAL LIST OF REGULATORY DOCUMENTS ON INDUSTRIAL SAFETY

Reference No.	Title	Year of Publication
AERB/SG/IS-1	Works Contract Safety	1992
AERB/SG/IS-2	Preparation of Safety Report of Industrial Plants other than Nuclear Power Plants in the Department of Atomic Energy	2001
AERB/SG/IS-3	Guidelines for Personal Protection Equipment	2004
AERB/SG/IS-4	Safety Guidelines for Pre-employment Medical Examination and Fitness for Special Assignments	2005
AERB/SG/IS-5	Safety Guidelines on Accelerators	2005
AERB/SG/IS-6	Safety in Thorium Mining and Milling	Under Preparation
AERB/SG/EP-3	Preparation of On-site Emergency Preparedness Plans for Non-Nuclear Installations	2000
AERB/SG/EP-4	Preparation of Off-site Emergency Preparedness Plans for Non-Nuclear Installations	2000
AERB/SM/IS-1	Safety Manual on Data Base Management for Accidents/Diseases Happening due to Occupation and Implementation of the same in the Department of Automic Energy	1991

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