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DRAFT IN WIDE CIRCULATION

Our Ref : CHD 08/T –IS 4906
Date : 01- 09- 2010

TECHNICAL COMMITTEE: OCCUPATIONAL HEALTH & SAFETY AND CHEMICAL HAZARDS SECTIONAL COMMITTEE, CHD 08

ADDRESSED TO:

1 **All Members of Occupational Health & Safety and Chemical Hazards Sectional Committee, CHD 08**
2. **All Members of Occupational Health & Safety Subcommittee, CHD 8:1**
3. **All Members of Chemical Hazards Subcommittee, CHD 8:2**
4. **All other concerned**

Dear Sir(s),

Please find enclosed the following draft Indian standard:

1 **DOC:CHD 08 (1823)C Draft Indian Standard ` CODE OF SAFETY FOR RADIOCHEMICAL LABORATORY (First Revision of IS 4906)'**

The documents are also hosted on BIS website www.bis.org.in. Kindly examine draft Indian Standards and forward your views stating any difficulties which you are likely to experience in your business or profession, if these are finally adopted as National Standards.

Last Date for Comment: 30 November 2010.

Comments, if any, may please be made in the format as given overleaf and mailed to the undersigned at the above address. In case no comments are received, we would presume your approval of the documents. However, in case we receive any comments on the document, the same shall be put up to the Sectional Committee for necessary action.
Thanking you,

Yours faithfully,

Encl: As above

(E.Devendar)
Scientist F & Head (Chemical)

BUREAU OF INDIAN STANDARDS

Draft Indian Standard

CODE OF SAFETY FOR RADIOCHEMICAL LABORATORY

(*First Revision of IS 4906*)

ICS 541.28.006.2.614.8

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Date **Price Group**

FOREWORD

((formal clauses to be added later)

0.1 This Indian Standard was first published in 1968. In preparing this standard, assistance had been derived from the following:

i. Report of International Commission on Radiological Protection Committee II on permissible dose for internal radiation 1959, Pergamon Press, New York.
ii. International directory of radio isotopes, Vol I, published by International Atomic Energy Agency, Vienna.
iii. International Commission on Radiological Protection (ICRP) Publication No. 6 (Amended and Revised 1962, 1964), Pergamon Press, Ne\v York.
iv. Recommendations of the International Commission on Radiological Protection. (Adopted September 17, 1965). ICRP Publication No. 9, Pergamon Press, New York.
v. A basic toxicity classification of radionuclides; Technical Report No. 15, International Atomic Energy Agency, Vienna, 1963.
vi. Basic safety standard for radiation protection, International Atomic Energy Agency, Vienna, 1967.
viii. Radioactive products, Bhabha Atomic Research Centre, Trombay, Bombay (AS).
ix. Manual of radiation protection in Bhabha- Atomic Research Centre, Trombay, Bombay (BARC/223); 1965.
x. Report of Committee V on the handling and disposal of radioactive materials in hospitals and medical research establishments, 1964; Pergamon Press, New York.

0.2 Radioisotopes are increasingly employed in medicines, agriculture and industry and in research laboratories. The maximum permissible concentrations of radionuclides in air and water are in almost all cases, excepting natural uranium, of orders of magnitude lower than the maximum allowable concentrations of non-active chemical isotopes. This, coupled with the characteristic radiotoxicity and difficulties of detection by conventional methods, makes it necessary that elaborate precautions are taken in the design and layout of radiochemical laboratories and in the handling, storage and disposal of radioactive materials.

0.3 The potential injuries due to radiation may be reduced to a minimum if all the safety instructions prescribed for the purpose are followed to the fullest extent. This is only possible if the characteristic of the radioactive material, nature of the hazards involved, purpose underlying the safety instruction and the function and uses of protective equipment are fully understood.

0.4 Radiation science is a very highly specialized field and a considerable amount of sustained research is being carried out throughout the world. As such concept and definitions change rather rapidly. Subject to this limitation, this code is based on best current opinion available on the subject.

0.5 Keeping in view the latest literature available on the subject, the following changes have been made in the standard:

i. quality factor has been changed as radiation weighting factor
ii. tissue weighting factor has been taken in to account for finding out the effect of radiation.
iii. Maximum Permissible Exposure Limit (Dose Limit) of Radiation has been changed
iv. Maximum Permissible level of surface contamination has been changed

0.6 Considerable assistance has been taken from the following literature while preparation of this standard.

i. 1990 Recommendations of the International Commission on Radiological Protection –ICRP Publication 60

ii. The 2007 Recommendations of the International Commission on Radiological Protection –ICRP Publication 103

iii. Safe Handling of Radionuclides, IAEA Safety Standards, Safety Series No.1, 1973

iv. International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, IAEA Safety Standards, Safety Series No. 115
Atomic Energy (Radiation Protection) Rules, 2004

v. Atomic Energy (Safe Disposal of Radioactive Wastes) Rules, 1987

vi. Atomic Energy Regulatory Board, Safety Manual on Radiation Protection for Nuclear Facilities, AERB/NF/ SM/O-2 (Rev.4), 2005

vii. Atomic Energy Regulatory Board, Safety Code for the Transport of Radioactive Materials, AERB/SC/TR-1, 1986

0.7 For prevention of chemical accidents, which may also occur in a radiochemical laboratory or which may lead to exposure due to radiation, Indian Standard Code of Safety for Chemical Laboratories, IS: 4209:1987 may be consulted.

1. SCOPE

1.1 This code recommends measures that should be adopted to prevent or minimize the exposure to ionizing radiation in a radiochemical laboratory handling small amounts of radioactive materials. It describes important characteristics of radioactive materials, nature of hazards, design requirements of laboratories and other essential information for protection against radiation.

2. MODES OF RADIATION EXPOSURE

2.1 In work places, exposure to radiation is by two modes:
(a) External exposure and (b) Internal exposure

2.1.1 External exposure is attributed to the sources that are external to the body. Alpha and low energy beta radiation do not cause any external exposure hazards whereas gamma radiation and neutron are mainly external exposure hazards. Examples of external exposures are exposure from a Co-60 gamma source and exposures due to cosmic radiations.

2.1.2 Internal exposure results from irradiation by sources inside the body. The pathways of internal exposure are: inhalation or ingestion of a radioactive material or absorption of radioactivity through skin and cuts/wounds. Inhalation of radon, thoron or tritiated vapors and exposure from radio nuclides deposited inside the body are examples of internal exposure. Alpha emitters are considered most toxic under this class of exposure.

3. BIOLOGICAL EFFECTS OF IONISING RADIATION

3.1 The process of ionization necessarily changes atoms, at least transiently and may thus alter the structure of the molecules containing them.

Molecular changes may also be caused by the excitation of atoms and molecules if the excitation energy exceeds the binding energy between atoms. If the affected molecules are in a living cell, the cell itself may sometimes be damaged, either directly if the molecule is critical to the cell's function or indirectly by causing chemical changes in adjacent molecules, e.g. the production of free radicals. Of the various forms of damage that radiation can cause in cells, the most important is that in the DNA. Damage in the DNA may prevent the survival or reproduction of the cell, but frequently the damage is repaired by the cell. If that repair is not perfect, it may result in a viable but modified cell. The occurrence and proliferation of a modified cell may well be influenced by other changes in the cell caused either before or after the exposure to radiation. Such influences are common and may include exposure to other carcinogens or mutagens.

3.2 If enough cells in an organ or tissue are killed or prevented from reproducing and functioning normally, there will be a loss of organ function - this effect is called deterministic effect. The loss of function become more serious as the number of affected cells is increased.

3.3 A modified somatic cell may still retain its reproductive capacity and may give rise to a clone of modified cells that may eventually result in a cancer. A modified germ cell in the gonads, with the functioning of transmitting genetic information to the descendants of an exposed individual, may transmit incorrect hereditary information and may cause severe harm to some of those descendants. These somatic and hereditary effects, which may start from a single modified cell are called stochastic effects.

3.4 The fundamental dosimetric quantity in radiological protection is the absorbed dose, D. This is the energy absorbed per unit mass. And its unit is the joule per kilogram which is given the special name gray (Gy).

3.5 The absorbed dose (energy absorbed per unit mass) is to be multiplied by radiation weighting factor, w_R to account for the relative effectiveness of different types of radiation in inducing health effects and is selected for the type and energy of the radiation incident on the body or, in the case of sources within the body, emitted by the source. This weighted absorbed dose is called equivalent dose. The unit is joule per kilogram with the special name sievert (Sv).

3.6 The effect of radiation also depends on the organ or tissue irradiated. The factor by which the equivalent dose in tissue or organ is weighted is called tissue weighting factor, w_T and the weighted equivalent dose is called effective dose. The unit is joule per kilogram with the special name sievert (Sv).

Table 1

Radiation Weighting Factors

Radiation type	Radiation weighting factor, W_R
Photons	1

Electrons and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy

Table 2

Tissue Weighting Factors

Tissue or organ	Tissue Weighting Factor W_T	Total
Bone marrow (red), Colon Lung, Stomach, Breast, Remainder *	0.12	0.72
Gonad	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary glands, Skin	0.01	0.04
	Total	1.00

* Remainder tissues: adrenals, extrathoracic region, gall bladder, heart, lymphatic nodes, small intestine, kidney, muscle, oral mucosa, pancreas, spleen, thymus, prostate, uterus/ cervix.

4. RADIATION DOSE LIMIT

4.1 The system of radiological protection aims at achieving the following objectives:

a) Prevention of detrimental deterministic effects and
b) Limiting the probability of stochastic effects.

It is based on the following three basic principles

a) No practice shall be adopted unless its introduction produces a positive net benefit to society (Justification of a practice);
b) All exposures shall be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account (optimization of protection) and
c) The normal exposure of individuals resulting from all relevant practices should be such that neither the total effective dose nor the equivalent dose to relevant

organs or tissues exceed the relevant dose limits to ensure that no individual is exposed to a risk that is judged to be unacceptable (dose limitation).

4.2 The exposures due to natural background radiation and medical procedures are excluded from the dose limits. The dose limits stipulated by Atomic Energy Regulatory Board (AERB) for the occupational exposure and general public are given below.

Table 3

Dose Limit

Category	Annual Effective Dose Limit(mSv)	Annual Equivalent Limit (mSv)			For consecutive 5 years (mSv)	Lifetime effective dose limit(Sv)
		Lens of eye	Skin	Extremities(hand & feet)		
Radiation worker	30	150	500	500	100	1
Apprentices & Trainees	6	50	150	150	-	-
Temporary Workers	15	75	250	250	-	-
Members of Public	1	15	50	-	-	-

4.3 For pregnant woman 2 mSv equivalent dose to abdomen for remainder of pregnancy and the limit on intake of radionuclides shall be 1/20 of the annual limit on intake.

4.4 Medical review when the cumulative occupational effective dose reaches 0.5 Sv

4.5 Internal exposures are to be controlled by applying the secondary limit called Annual Limit on intakes. This would correspond to an intake, which would result in a committed effective dose of 20 mSv. The limit on intake for individual radionuclides shall be 1 ALI for each year. The ALI values for important radionuclides are given in the Appendix B.

4.6 Derived Air Concentration values of individual radionuclides are used for controlling the internal exposures due to inhalation. DAC of a radionuclide in Bq m^{-3} of air is given by

$$\text{DAC} = \frac{\text{ALI of the radionuclide (for inhalation)}}{2.4\times10^{3}}$$

where 2.4×10^3 m^3 is the volume of air inhaled by International Commission on Radiological Protection (ICRP) reference man in a year during working hours.

5. CLASSIFICATION OF RADIOISOTOPES

5.1 Radionuclides are classified into four groups according to relative radiotoxicity per unit activity. Appendix A gives International Atomic Energy Agency (IAEA) classification of radioisotopes into Group I (Very high radiotoxicity), Group II (High radiotoxicity), Group III (Moderate radiotoxicity) and Group IV (Low radiotoxicity).

6. RADIATION SOURCES

6.1 The radiation sources in use may be classified as:

a) *Sealed Sources* - which do not contribute to contamination or internal hazard, and remain a primary source.
b) *Open Sources* - which are used for secondary preparations through dilutions, labelling, etc.

6.1.1 Sealed Sources - Sealed sources are employed in a number of fields, such as teletherapy, interstitial therapy, industrial gamma radiography, thickness gauging, static eliminators and for calibration purposes. Co-60, Ir-192, Cs-137, Sr-90, Tl-204, etc, are some of the more common sources which are industrially used. Such sources are normally sealed in capsules to prevent the escape of the radioactive material and should be ensured against breakage or defective sealing. In case of properly sealed sources, the hazard arises only through external exposure, and against this the greatest precaution should be used.

6.1.1.1 Choice of sealed sources - The activity of the source should be as low as possible and not in very much excess of the requirements, with due regard to its half life and duration of use. The radioactive material inside the sealed container should be of low toxicity, and in such chemical and physical form as to minimize dispersion or ingestion, in case of rupture of the container. Sealed sources should have clear markings indicating the nature and quantity of the source activity. These sources should be periodically checked up for any contamination or leakage, particularly in case of radium whose daughter product radon is a gas which could be quite hazardous when inhaled. A recommended test is to scrub the dry container with a dry filter paper sponge and to count the activity. Mechanically damaged or corroded sources should be immediately placed in suitable containers and sealed. Appropriate procedure for disposal of these sources should be practiced.

6.1.1.2 Precautions in the use of sealed sources - The basic objective of all radiation protection measures is based on ALARA principle. Measures should be taken to prevent personnel handling sources from receiving radiation doses in excess of the prescribed regulatory limits. All efforts should be made to prevent inadvertent radiation exposures. This is achieved by a suitable combination of the following factors:

a) Time - By limiting the time of exposure while handling the sealed source;
b) Shielding - By the use of adequate shielding in between the active source and the worker; and
c) Distance-By maintaining a maximum possible distance between the source and the worker, by using long forceps and remote handling equipment.

By making use of these factors in appropriate combination, radiation exposure to personnel not only engaged on actual work, but in the surroundings also, could be reduced to the minimum.

6.1.1.3 It is very important that while working with any sealed radiation source, adequate shielding should be provided and the adequacy should always be tested by direct measurements. Precautions should be taken to guard against any scattered radiation around the primary protective shielding. The eyes, face and body may be protected from beta rays by transparent plates of perspex of moderate thickness. Protection against gamma rays should be achieved by screening the source with adequate shielding of lead which should be as near the source as possible. The lead bricks used for shielding sources should overlap to prevent penetration of radiation through gaps. In addition to lead, concrete and marble also offer adequate protection against gamma radiation, but lead is the most convenient.

6.1.1.4 Forceps used for handling these sources should be as long as practicable and should grip the source with minimum force exerted by the fingers. These forceps should be light in weight and should have grips notched or grooved in a way to hold the sources securely. Transparent plastic hand shields of sufficient thickness attached to the forceps would be an added protection against the most energetic betas, if unshielded beta emitters are being used. The time of handling these sources should be minimum possible, if unshielded radiation sources are being used. For pipetting solutions of very high activity and presenting over exposure hazards in handling, remote handling pipette should be utilized over the shielding wall.

6.1.1.5 Vices, chucks or similar arrangement should be provided at the protective barriers, to facilitate handling of sources. They should be designed against excessive clamping pressure which will lead to damaging the sources. A spring loaded ratchet or slipping clutch mechanism would prove useful.

6.1.1.6 Some of the regulations to be observed in the application of the sealed sources are given briefly below.

a) Industrial gamma radiography-*The* controlled area should be clearly marked with instructions restricting entry to unauthorised personnel. Light or audible signals or both should, be provided during irradiation. The radiographic set-up should be completed before starting the irradiation. Any radiographic work requiring removal of the sealed source from shielding container should be preceded by adjustments with a dummy capsule. The removal of the source from the shielding container should be done by automatic means or by remote handling. After return of the source to the container, the shielding should be verified by monitoring.

b) Thickness, gauges, static eliminators and similar devices using sealed sources - Wherever possible sealed sources should be installed or shielded in such a way that radiation exposure to the personnel installing or maintaining it is within the stipulated dose limit and should be ensured ALARA. Radioactive symbols should be put up permanently on such devices. In case of loss or breakage of the source, the *Radiological Safety Officer (RSO) should be notified immediately.

**As per the Atomic Energy Radiation Protection Rules, 2004 every employer shall designate a person having appropriate qualification as RSO with the written approval of the Competent Authority*

6.1.1.7 Teletherapy and interstitial therapy installations in medical departments need elaborate planning and form a separate subject altogether.

6.1.1.8 Method of Use of sealed sources - Source should be properly stored and inventories maintained. If any person has reason to believe that a source has been lost he should report immediately to the RSO for initiating proper actions. All sources should be manipulated in such a way as to minimize exposure of personnel and people in adjacent area. Area of particular hazard should be cordoned off. Any semi-shielded beam or scattered beam should be clearly indicated, and area monitored to assess the radiation fields. Sealed sources, when practicable, should be used in enclosed installations and should never be touched with hand. In addition to adequate shielding, limiting the working time also helps to minimise the exposure as possible and for this dummy runs should be performed beforehand. These protection measures require careful planning and proper application of radiation protection principles.

6.1.2 Unsealed or Open Sources - The open sources offer a comparatively larger scope of work and are employed in tracer studies and preparation of labelled compounds. They present problems of safety in handling and are a potential source of contamination in the laboratories. In manipulating an unsealed or open radioactive source great care should be exercised towards minimizing the chances of entry into the body as a result of ingestion and inhalation of air-borne particles and absorption through skin. The hazards will arise in general through contaminated hands, smoking and mouth pipetting, glass blowing, etc, or from inhalation of air-borne radioactivity. When the hazards due to ingestion and inhalation are negligible (as in the case of well sealed sources) the risks in handling radioisotopes will depend essentially upon the effects of external beta and gamma radiation.

6.2 Authorisation: Radioisotopes can be procured and handled only by the users duly authorized by the regulatory body. Lay out of the radiochemical lab should be approved by the regulatory body. The transportation of the source shall also be subject to the requirements of the regulatory body with due applicable procedures for safe transport of radioactive materials. Qualified experts should be appointed for the safe handling of the sources as per the qualification procedures prescribed by AERB.

6.3 Safety Aspects

a) All the radioactive sources should be kept secured so as to prevent theft or damage and to prevent any unauthorized handling;

b) All radioactive sources (wherever applicable) should be incorporated with safety devices such that the magnitude of likelihood of individual and collective exposure are ALARA;

c) Suitable arrangement shall be made for any source or practice.

  i) to prevent, as far as possible, any accident, occurrence or incident that could be reasonably foreseen in connection with the source or the practice
  ii) to limit the consequences of any accident, occurrence or incident that does occur
  iii) to provide workers with the information, training and equipment necessary to restrict their potential exposures
  iv) to ensure that there be adequate procedure for the control of the source and of any potential accident that could reasonably be foreseen

d) An accountability system shall be maintained that includes records of -
  i) the location and description of the sources and
  ii) the activity form of each radioactive substance

7. CLASSIFICATION OF LABORATORIES

7.1 The laboratories have been classified as Type A, B and C based on the safety requirements for handling different quantities of open sources in a wide range of operation and facilities available. For low level radiochemical work type C laboratory is quite adequate. Depending upon the toxicity, one can handle upto 0.37 GBq (10 mCi) of radioactive material in such a facility. For larger amounts, facilities must be upgraded to meet the requirements of type B or type A laboratories. The quantities of radionuclides that can be handled with reasonable safety in different types of laboratories will also depend on whether operations are normal chemical, complex wet, simple dry or dry and dusty.

7.1.1 The quantities of radioactive materials of different toxicity groups that can be handled in the three types of laboratories mentioned above are given in Table 4. These figures provide general guidelines. They are subject to modification depending on the complexity of operations involved. Depending upon the nature of operation carried out, modifying factors are used to arrive at the maximum amount of activity that can be handled in given handling facility. These modifying factors are given in Table 5.

Table 4

Quantities of radioisotopes permitted for handling in different types of laboratories

	Type of Lab
	--

Radiotoxicity of radionuclides	Type C	Type B	Type A
Very high	0.37 MBq or less (10 µCi)	0.37 MBq - 0.37 GBq (10 µCi - 10 mCi)	0.37 GBq or more (10 mCi)
High	3.7 MBq or less (100 µCi)	3.7 MBq - 3.7 GBq (100 µCi - 100 mCi)	3.7 GBq or more (100 mCi)
Moderate	37 MBq or less (1mCi)	37 MBq - 37 GBq (1 mCi - 1Ci)	37 GBq or more (1Ci)
Low	0.37 GBq or less (10 mCi)	0.37 GBq - 370 GBq (10 mCi – 10 Ci)	370 GBq or more (10 Ci)

Table 5

Modifying factors applicable to various operations

Nature of operation	Modifying factor
i) Simple storage (say of stock solution)	x 100
ii) Very simple wet operations (dilution, ion exchange etc.)	x 10
iii) Normal chemical operations	x 1
iv) Complex wet operations (with risk of spillage) or simple dry operations	x 0.1
v) Dry and dusty operations	x 0.01

7.1.2 At the present stage of development and utilization of the radioisotopes in the country, Type A laboratories are not likely to come up in outside the Department of Atomic Energy or its allied units. However, there are a couple of laboratories which can be classified as Type B or Type C laboratories, which are common in medical and agriculture institutions, industrial establishments and universities.

7.2 Design Features of the laboratories

7.2.1 Type C Labs

This type of laboratory is adequate for radiochemistry experiments at the university level and for low level radiochemical work in research institution. Any college laboratory, with minimal effort and investment, can become a Type C laboratory by making following provisions. Judicious consideration should be given to (a) radiation safety, (b) efficiency of the operations, (c) convenience and (d) economy.

i) ***Layout -*** As far as possible, active laboratories should be designed in such a way as to segregate from other inactive laboratories. Working space in this type of laboratory should be allotted on generous scale as compared to a normal chemical laboratory. Sufficient storage space should be provided for stocking radioactive solutions. Washing facilities in general are adequately complied with by use of the ordinary laboratory sinks with a smooth white glass finish without cracks. The discharge of liquid radioactive waste, with proper authorization, should be limited to one or two drains, if possible and should be properly planned to pass through areas away from work places. These drains should be of plastic or polyethylene pipe that could be easily repaired and should lead to sewers or collecting carboys or tanks.

ii) ***Floors, Walls, Ceilings and Surfaces -*** These should be amenable for easy decontamination, These should have a smooth and as far possible joint free finish, e.g. floor can be covered with linoleum or PVC tiles; walls and ceilings can be painted with washable paint. Smooth panels should cover electrical conduits and other piping work or else they too should be painted with washable paint. Similarly wooden furniture will be replaced by painted steel furniture. Where this is not possible, exposed wooden surfaces shall be given "sunmica" type finish. All working surfaces including fume hoods should be strong enough to support the gamma shields, viz. lead bricks. Floors should be cleaned by wet mopping and should not be swept dry. Walls and ceilings should be finished with a non-porous washable surface, such as a good hard gloss paint.

(iii) Decontamination/Washing Facility - Each laboratory shall be provided with a stainless steel sink. In its absence, porcelain sink is considered acceptable. The taps should be elbow / foot operated so as not to contaminate them by hands or gloves.

(iv) Laboratory Liquid Effluent - The average radioactivity content of the effluent from these laboratories is generally quite low (<0.37 MBq or 10.0μCi/m^3) and the waste volume is also small. It can therefore be allowed to mix with general building effluent from the locality. These other effluents easily provide a dilution factor of 100 or more, thus rendering it inactive for all practical purposes. Separate waste management arrangements are not required.

(v) **Forced Ventilation -** The laboratory should be provided with 3 or more air changes per hour. This air should be exhausted through the fume hood(s), which should have an exhaust fan with adequate capacity to provide a minimum linear velocity of 30-meter min^{-1} when the sash front has a standard opening of 30 cm. The fume hoods should be preferably located near the external wall of the building with adjoining open space. It is sufficient to discharge the exhaust air through ducting to the outside of the building at a point above roof level or at least not immediately adjacent to windows or air intakes.

The exhaust from fumehood(s) is thus discharged directly to the atmosphere. The average radioactivity level in the discharged air is generally quite low (<3.7 Bq/m3) and filtration of this air is not called for. Due care should be given when considering the design and erection of the exhaust duct towards ease of replacement as well as minimizing the spread of contamination within building during dismantling operations. For example the duct length could be as short as possible and the single piece and the exhaust fan should be mounted on the outside of the ducting to reduce contamination of the motor and to make it more accessible for maintenance purpose. Fume hoods should produce a regular flow without any eddies. The speed of the airflow should be such that there can be no escapes of air into the work place from the fume hood under typical operating conditions.

(vi) **Counting Room Facility** -A separate room for housing counting equipment is preferred to avoid any cross contaminations. In the absence of this a portion of the laboratory should be segregated by partitions and converted into a counting room.

(vii) **Storage Facility** - If several radioisotopes are involved in radiochemical work, a separate storage place (in one corner of the room) should be created. Further, if the storage area becomes a source of radiation (giving a dose of 10 μSvh^{-1} or more at 10 cm distance) some provision for lead shielding should be made. This will be all the more necessary, if a part of the laboratory has been converted into a counting room, to suppress counter background

(viii) **Monitoring Instruments** - In any radioactive laboratory, incidents of personnel, equipment or surface contamination do occur once in a while. To tackle such situations and bring them under control, provision of suitable monitoring instruments must be made. The list includes a Geiger Muller (G.M) survey meter and an alpha/ beta-gamma contamination monitor as minimum instruments required. More instruments can be added to the list to suit local requirements such as area monitoring for beta gamma radiation. Personnel may be provided with Thermo Luminescent Dosimeter (TLD)/Film badges depending on the advice of the RSO.

(ix) **Provision of Simple Handling Equipment** - It is necessary to carry out the jobs properly and quickly but at the same time ensuring that the possibility of contamination is reduced. The list includes capping/recapping tool, tweezers, small tongs, syringes, pro-pipettes, etc.

7.2.2 Type B Laboratories

This type of facility becomes essential when the quantities of radioactive materials being handled exceed frequently the limits prescribed for type C laboratories. If the limits are exceed by factors less than an order of magnitude, the type B laboratory will be a simple modified version of a type C laboratory. For larger amounts, a separate facility coming under type B laboratory must be designed.

Type B laboratory meets all the specifications of a type C laboratory. In addition the following points need careful evaluation for upgradation/incorporation.

(i) **Ventilation System** - The ventilation system for the active area must be independent of the other ventilation systems in the building. It may also be necessary to provide for the filtration of the fume hood exhaust air before it is released into the atmosphere. This exhaust air should be released at the tallest point of the building or a few meters above it through a small stack. Siting of exhaust and supply points should be so chosen to prevent recirculation of exhausted air under the prevailing conditions of local terrain. The degree of filtration of the exhaust air will have to be worked out in advance and suitable filtration system installed accordingly. The capacity of the ventilation system should be adequate to provide 5-7 air changes/h in the laboratories.

(ii) **Use of gloves boxes** - Radioactive operations are shifted from fume hoods to gloves boxes whenever the quantities of radioactive materials involved exceed the limits set for operations in fume hood or wherever materials are handled in dry form. Glove boxes are discussed under containment systems.

(iii) **Gamma Shielding** - This may be necessary for creating a regular storage facility or providing shielding in a fume hood or glove box if the radiation fields for personnel working in operating areas exceed the derived working limits. For the storage area the floor loading capacity should be adequate to support the weight of lead or mild steel, which are commonly used for gamma shielding. This requirement should be considered while facility is under construction. Similarly, the fume hood/glove box floor or the tables used to support them should be strong enough to support the weight of the lead bricks used to make shielded enclosures within these handling facilities. Areas requiring heavy gamma shielding are always located on the ground floor.

(iv) **Provision of a Change Room** - Type B laboratories require provision of a change room at the entrance of the active area, which is delineated by providing a physical barrier. Shoe covers must be worn beyond the barrier and laboratory coats must be picked up from the change room before proceeding to the laboratories. Washbasins and contamination monitors are also installed in the change room.

(v) **Laboratory Liquid Effluents** - The activity content of the waste arising from these laboratories may be high enough to prohibit its discharge directly into the public sewer. This problem is tackled by taking following steps (a). Efforts are to be made to collect high active liquid waste into separate plastic carboys or glass bottles instead of discharging it directly into the sink. Such waste is then allowed to decay by storage or handed over to a centralized waste management facility and (b) by providing a separate liquid effluent delay/holdup tank can be analyzed for its activity level and then discharged into public sewer directly if the activity level is within limits or after dilution if the activity level is high.

(vi) **Provision of Additional Monitoring Instruments/Protective Equipments** - The first and foremost in this case is providing hand, foot and clothing monitors. Provision for routine air monitoring in critical laboratory areas should also be made. Respiratory protective equipment, i.e., dust respirators should also be made available in the change room for use when required. TLD/Film badges may also become necessary for all individuals in the laboratory.

For type B facilities outside Department of Atomic Energy (DAE), a constant interaction may be necessary between operating agency and the regulatory agency (AERB) to deal with situations not clearly spelt out otherwise.

7.2.3 Type A Laboratory

Type A laboratories require careful planning and design, as there is virtually no upper limit on the materials that can be handled there. Each project work is therefore examined separately and the largest quantities of materials likely to be encountered are identified. Necessary facilities are then built accordingly taking into account the operational requirements.

Thus all the specifications discussed above in the case of type C and B facilities must be met in this case. In addition the following points require careful consideration.

(i) **Layout of the Laboratory Area** - From consideration of safety and operational efficiency, the design of overall laboratory should be in such a way to group together areas according to the degree of contamination hazard posed by them. Such grouping involves classification of areas into various zones as described below.

(a) White (inactive) Area - It consists of unrestricted areas of the laboratory facility e.g. office room, reception room, workshop, etc. No radioactive material is kept, stored or handled here. Probability of contamination is nil in this area except under accidental conditions.

(b) Green (Potentially active) Area - No radioactive materials are handled in this area but small quantities in sealed containers may be stored. Possibility of contamination in this area (which is otherwise clean) can not be ruled out by virtue of its proximity to active areas. Counting room, health physics room, personnel corridors, etc. constitute this zone. Access to this and other areas described below is restricted to laboratory staff and the supporting staff only.

The boundary between white and green zones is not sharp but the laboratory is so designed that a barrier can be located to indicate the beginning of green area if the need arises.

(c) Amber (low active) Area - It is the actual laboratory area where workbenches, fume hoods, glove boxes, etc. are located. It also includes the active personnel corridors and the change room. Possibility of contamination in this area always exists by virtue of its proximity to red zone. A physical barrier separates it from the green zone.

(d) Red (active) Area - The area where the radioactive material is actually present and handled, i.e., interior of a fumehood, glove box or shielded cell. This zone is always highly contaminated and personnel standing in amber area manipulate operations here. Entry in this area is forbidden except under special circumstances and with proper authorization in the form of special work permits.
The zoning in type B and C labs are also same. While red zone gets really demarcated, boundaries of other zones are less rigid.

(ii) **Containment System** - The spread of activity or contamination from red zone to amber zone is prevented /minimized by designing the red zone as containment system. It consists of the following:

A) Fumehood - Fume hood is a partial enclosure and the opening of the panel provides an access to the material being handled. Directional air movement through the panel opening maintained at 30 cm from the bottom prevents the materials from reaching operators' environment. Operations are carried out in fume hood when the amounts of radioactive materials being handled are limited, nature of operation is simple and contamination hazard is not significant.

B) Glove Box - A glove box is a miniature laboratory within a laboratory. It provides for total containment of material being manipulated. It is leak tight assembly, which completely isolates the hazardous material from the operator's environment. It is operated at a negative pressure of 12-25 mm water gauge. The manipulation is effected through gauntlet gloves fixed on the viewing panels of glove box. Transfer ports and bagging ports are provided on glove boxes for taking the materials in or out without affecting containment's integrity. Glove boxes are used when the activities handled exceed the limits prescribed for fume hoods or when the nature of operation is hazardous.

C) Shielded glove boxes and hot cells are essentially extended versions of glove boxes. Thus they provide not only total containment of materials being handled but also provide shielding to personnel when radiation levels encountered are high. The high radiation levels in these cases preclude operations by hands through gauntlet gloves. The operations are then carried out by tongs and master slave manipulators in shielded glove boxes and hot cells respectively.

(iii) **Ventilation System** - The ventilation system is the most important and expensive part of the entire radioactive laboratory system. The general ventilation system in a laboratory consists of a balanced air supply and exhaust, such that the air always flows from potentially less active to high active area. The quantum of air supply and exhaust (number of air changes) is governed primarily by the number of fume hoods provided in the laboratory. The inlet air is filtered to avoid large dust loads. Filtration of the exhaust air is determined on the basis of likely release of materials into the atmosphere. Separate systems are provided for laboratory areas (which include fume hoods), glove boxes (including shielded boxes) and hot cells.

The ventilation system in a class A laboratory has a once through conditioned air supply system. The general laboratory ventilation system consists of a balanced supply and exhaust. The airflow always follows the pattern: from white area to green area to amber area to red area. This tends to prevent spread of air borne contamination. The capacity of the ventilation system should be adequate to provide about 3, 5 and 10 air changes in white, green and amber areas respectively. This large air-volume can pose dust problems in the active laboratories. The supply air is therefore filtered through coarse filters which removes 85 to 95% of the atmospheric dust load. This air is exhausted through fume hoods. Since the quantities of activities handled in fume hoods are relatively large (as compared to those in type B or C laboratories), the exhausted air is filtered through a bank of high efficiency particulate air (HEPA) filters which has a filtration/retention efficiency of greater than 99.5% (for the bank as a whole) for particles of 0.3 μm size (for individual filters the efficiency is $\geq$99.98%). The filtered air is released to the atmosphere through a stack, which should be taller than the tallest building in that area.

The glove box and hot cell exhaust systems has no separate air supply. They draw air from the surrounding areas through leakages and in certain cases, through designed air inlet points. Since the activities handled in these enclosures are very high, the exhausted air undergoes filtration through HEPA filters twice: first while leaving the enclosure and second before discharging to stack. The stack height is decided based on dilution needed for the exhausted air by the time it reaches ground level.

Because the type A laboratories are very expensive facilities, their continuous operation and utilization is very essential. For this purpose, the ventilation systems generally have 50% to 100% standby capacities to take care of any breakdowns/shutdowns. The glove box and hot cell ventilation system also have standby diesel power supply, which takes over if and when normal power supply fails.

(iv) **Liquid Effluent System** - From type A laboratories, no effluent is discharged directly into the public sewers or into the sea or river. These laboratories have their low liquid waste systems, which consist of waste lines and storage tanks. The collected effluents are monitored for their activity content and then pumped to effluent treatment plant for further treatment and discharge. This waste contains both alpha and beta gamma activities.

All the high level liquid waste which can not be directly put into the sinks are taken in carboys and separately handed over to Waste Management Facility for further treatment. Alpha bearing waste is collected separately.

v) **Solid Radioactive Wastes** - All the waste arising from red and amber zones is treated as active waste. It consists of gloves, tissue paper, polyethylene sheets, glassware and anything else in the laboratory that has been used for active work and is no longer required. Waste is segregated in two categories (i) compressible waste consisting of paper, rubber, PVC etc. and (ii) non-compressible waste consisting of glass, metal, etc. A further categorization is also made based on radiation levels i.e. <2, 2-20 and > 20 mSv/h for beta-gamma waste. Alpha bearing waste is collected separately.

The waste is doubly sealed in polyethylene bags to withstand rough handling during transportation. All non-compressible waste requires further packing in cardboard boxes. Each waste bag must have a proper transit tag that shows the waste category and the level of radiation field on its surface. The waste from type A laboratories is always handed over to a centralized waste management facility for further treatment.

Waste management, should be in accordance with the regulatory requirements stipulated for various types of laboratories.

7.3 Laboratory techniques and equipment

7.3.1 Choice of Process - The quantity of radicactive material chosen for any specific purpose should not be greater than the minimum dictated by experimental needs. It is preferable to work with solutions rather than dry powdery materials. The manipulation processes selected should be those which avoid excessive transfers from one vessel to another.

7.3.2 Equipment - Special equipment consisting of tongs, forceps, trays and for the higher levels of gamma-activity apparatus, with adequate shielding should be provided. All equipment used or handling radioactive materials should be confined to the activity area and should be treated as contaminated.

7.3.3 Containers for active materials should as far as possible incorporate necessary shielding close to the source. Pipetting of solutions and operation of wash bottles should never be performed by mouth, but by means of compression bulbs and by remote handling equipment wherever necessary. Glass-blowing on contaminated apparatus shall be done with special –techniques which do not involve mouth operations. Squeeze type wash bottles and propipettes are useful for those operations.

7.3.4 Storage Cell - In addition to active *areas,* the laboratory should have provision for a well designed cubicle for storing radioactive sources. The area should be designed with some understanding of utilization of sources.

7.3.5 Decontamination Procedures - In any establishment using radioisotopes, contamination either direct or indirect is unavoidable in spite of the stringent measures adopted to prevent it. The types of contaminations which are common to any radioisotope laboratory are of three types:

a) Personnel contamination
b) Equipment contamination, and
c) Work area contamination.

Decontamination of each type mentioned above may be achieved by careful manipulation of a set of procedures outlined below:

7.3.5.1 Personnel Decontamination - Personal cleanliness should be watched in all operations where there is a likelihood of even the slightest contamination; persons working with radioisotopes (including those of low toxicity) should wash their hands thoroughly with detergents before leaving the work area, either temporarily or at the end of the working period. Particular attention should be paid to the finger nails. After washing, the contaminated parts should be checked rigorously for any fixed residual contamination. Table 6 specifies the permissible levels of surface contamination. For instance if washing with detergents and water fails to bring down the level of contamination below permissible level, say in the case of hand, other methods should be tried. One may resort to treatment with suitable chemicals, such as potassium permanganate and sodium bisulphite or EDTA solution. However, chemical treatment should be conducted carefully because this will enhance chances of uptake through porous skin. Even mild abrasions or scrubbing shall be done with soft nylon brush in such a way as not to injure the skin. However, treatment with chemicals shall always be done with utmost discretion depending upon the site of contamination and only under medical supervision. For example, any contamination in the eye or near the eye should be removed only with water and not chemicals. Similarly treatment of face and other sensitive organs should be conducted with greatest caution and on proper supervision of the authorized physician. Care shall be taken to avoid contamination of abrasions, cuts and puncture wounds and any person with any of these handicaps shall not be allowed to work with radioisotope, without proper sealing of the open wound. If skin break or cut occurs while working in an active area, the authorities concerned shall be informed immediately for contamination check-up and further decontamination. Needless to say, a medical officer should be consulted in all cases of contamination of cuts and sores.

Table 6

MAXIMUM PERMISSIBLE LEVELS OF SURFACE CONTAMINATION

Derived Working Levels (DWL) for Radioactive Contamination

Surface	Beta emitters (Bq/cm^2)	Alpha emitters (Bq/cm^2)
Skin	1.5	1.0
Hands	350	250

Clothes:		
Plant	6	2
Personal	2	0.5
Shoes:		
Plant	37	3.7
Personal	0.37	0.037
Floor	3.7	0.37

Note: Limits apply to fixed contamination on skin and personal clothing

7.3.5.2 Decontamination of laboratory equipment and work areas – Any equipment which has been used ir connection with any radioactive work should be treated as contaminated unless proved otherwise by a careful survey. The types of decontamination treatment will depend upon the nature of contaminant and upon the type of surface contaminated:

a) Glassware may be cleaned on a routine basis with chromic acid solution. If unsuccessful, other cleaning agents, such as concentrated nitric acid, ammonium citrate, penta sodium triphosphate and ammonium bifluoride should be tried. The solutions used for cleaning should be disposed off adequately as active waste (see 8).
b) All metal objects may be cleaned by washing with a detergent solution followed, if necessary, with dilute nitric acid or a 10 percent solution of sodium citrate or ammonium bifluoride. In the case of stainless steel hydrochloric acid should be avoided as this will result in corrosion leading to greater difficulty in future decontamination work. Brass polish for brass, oxalic acid for rusty surfaces, ammonium citrate, dilute acids and organic solvents are also recommended for decontamination purposes.
c) Though plastic paint surfaces may be decontaminated often successfully by using acetone, trichloroethylene or a 10 percent hydrochloric acid solution, it is advisable to strip off the paint and replace with new coatings.
d) The above mentioned procedures are mostly for wet spillage on various surfaces. However, if a dry contamination occurs on any surface, as a first step in the process of decontamination a vacuum cleaner with a high efficiency filter should be used followed by suitable methods mentioned above.
e) Protective apparel and personal clothing of staff or clothing, bedding of hospital patients who are being treated with radioisotopes shall be monitored regularly. If there is any significant contamination, they should be segregated and stored until the activity has fallen below the safe level as recommended in Table 2, failing which they should be laundered in a special laundering facility or discarded.

7.3.6 Wash Room and Change Rooms - Every facility handling radioactivity should be equipped with change rooms at entry and wash room near the working place. The change room is a place where on entry into the building the worker changes into company clothing or overalls as required and goes into the hot areas. At the time of leaving working area, he passes through the change rooms, is monitored and then wears his personal clothing. Change room is also equipped with showers as well as decontamination solution. A change room acts as a barrier against movement of radioactive contamination outside working areas. Washrooms equipped with showers should be installed in a facility. These would facilitate immediate cleanup in case of sudden spills, or suspected contamination.

8.0 Radioactive waste disposal

8.1 Operations in a radiochemical laboratory result in the generation of radioactive wastes. All the operations should be carried out in such a way that the amount of waste is minimized by appropriate use of methods and management procedures.

8.1.1 Solid wastes: The solid wastes may comprise of mops/gloves, filter paper containing precipitates, tissue papers, contaminated glass apparatus, cotton etc. These are segregated as inflammables/ compressible or non-compressible. The wastes are collected in polyethylene /PVC bags and packed in suitable containers and monitored for its radioactivity. It is then properly tagged. The waste packets should be characterized with respect to its contents and activity to ensure compliance with regulatory requirements.

The wastes should not be disposed off to the environment directly. The disposal should be in accordance with the regulatory stipulations as mentioned before. Authorization from the regulatory body should be obtained before disposal/transfer of radioactive wastes under the Atomic Energy (Safe Disposal of radioactive Wastes Rules), 1987, G.S.R. 125.

8.1.2 Liquid wastes**:** Radiochemical laboratories should be properly designed to handle liquid waste so as to have no leakage to environment and contamination in the facility. Very low levels of radioactive liquid effluents can be directly discharged to the sink which drains to liquid waste hold up tank or delay tank which after activity assessment can either be discharged to the environment directly or transferred to the waste management facility. The disposal limit for the discharges should conform to those prescribed by the regulatory body.

8.1.3 Gaseous effluents: The gaseous effluents from the laboratory are exhausted through a suitable ventilation system to the environment. The gaseous radioactive effluents evolved from the fume hood and glove boxes should be monitored before discharge to the environment. Adequate gas cleaning system should be provided to ensure that the discharges of airborne releases are within the authorized limits of AERB.

8.2 In order to ensure safe transport, relevant regulations in ‘Safety Code for the Transport of Radioactive Materials, AERB/SC/TR-1, 1986’ should be followed for properly packing the radioactive waste to be transported. For any major problems connected with the safety of handling and disposal of radioactive materials, advice may be sought from Atomic Energy Regulatory Board, Mumbai.

9.0 Radiation Monitoring Instruments

9.1 Radiation monitoring includes various radiological measurements and also the interpretation of these so as to achieve controls in internal and external exposure of personnel.

9.2 Workplace monitoring consisting of external radiation field monitoring and surface contamination monitoring should be done regularly to evaluate the radiological conditions and also to have an assessment of personnel exposure. Routine personnel monitoring for external and internal exposures as applicable should be carried out and personnel dose records should be maintained

9.3 Radiation monitoring is provided by persons/ institutions approved by the regulatory body.

9.4 External exposure of radiation workers is monitored routinely for all types of radiation which can cause exposure using appropriate dosimeters. Any internal exposures can be measured by bioassay or by whole body counting. Details of these monitoring services can be obtained from Health, Safety and Environment Group, Bhabha Atomic Research Centre, Mumbai.

9.5 Workplace monitoring for external radiation is carried out using a portable or fixed beta gamma monitors. Monitoring of airborne contamination is carried out by sampling radioactivity using a high capacity air sampling vacuum pump (500-1000 lpm). The filter paper is then counted for gross beta or alpha activity. Air concentration is then assessed by applying proper efficiency correction. Proper respirators like half mask, full face mask, etc is used if the air concentration is above the prescribed DAC values. External contamination of workers is assessed using suitable contamination monitors. Proper decontamination procedures have to be followed if loose contamination is observed on clothing, hands, or on person.

10 General Safety Rules

10.1 A good safety culture in the laboratory would help control radiation exposure and contamination control. Good working practices are summarized below:

i) Laboratory coats should be worn in laboratory
ii) Unnecessary materials should not be accumulated in the laboratory
iii) The movement and storage of radioactive material shall be under the control of a responsible person acquainted with safety procedures and regulations
iv) The maintenance of an inventory of radioactive sources is very necessary
v) Eating, smoking and drinking are prohibited in the laboratory
vi) No mouth operation are allowed, for example, pipettes, wash bottles and labels shall not be put in the mouth
vii) Solid and liquid waste materials shall be monitored and segregated properly.
viii) When wearing gloves disposable tissues should be used for handling taps, switches etc
ix) Gloves, clothing, apparatus and benches shall be monitored after work with radioactive materials.
x) Radioactive work should not be undertaken by a person having open cuts/wounds

xi) TLD badges/dosimeters shall be worn on person and a record of the external dose received by the person shall be maintained
xii) Radiation symbols shall be posted wherever active sources are handled.
xiii) Contaminated areas should be cordoned off
xiv) A radiochemical laboratory should not be used as a normal sitting place

10.2 Health surveillance

Health surveillance programme shall be based on the general principles of occupational health and designed to assess the initial and continuing fitness of the worker for the tasks

10.2.1 Pre-employment Medical Examination

This shall be done for all the radiation workers. The medical records shall include family and personal history, previous occupational history and previous X-ray diagnostic examination or radiation therapy and clinical investigations.

10.2.2 Periodic Medical examination

All radiation workers shall be medically examined at least once in five years. Individuals who would require a change or restriction in the job allocation, on the basis of their health status, will be indicated in the medical report submitted to the lab-in-charge with a copy to the radiological safety officer. The relevant information on the restrictions should also be given to the individual worker concerned whenever required so that the worker is aware of it.

11. TRAINING, INDOCTRINATION AND SAFETY SUPERVISION

11.1 An important contributory factor in safety is the training and indoctrination given to the worker in radiation hazards and safety code of practice. For any new installation it is important that the staff should be given lectures and demonstration in the use of personnel monitoring equipment and good housekeeping methods by a trained health physicist. There are regular training facilities with the Bhabha Atomic Research Centre, Trombay, Mumbai for imparting the necessary knowledge and practical experience. The trained health physicist or the health supervisor should conduct in turn periodical refresher courses and maintain a record of personal exposures.

11.2 Safety Supervision - The authority in charge of radiochemical laboratory shall identify a technically competent person or persons to provide advice on all relevant aspects of radiation protection and to provide such technical services as required in the application of appropriate recommendation for radiation protection and maintain exposure records as required by the safety code and national radiation safety practices.

12. PROTECTIVE MEASURES

12.1 Equipment - External radiation hazards may be minimized by making use of special equipment, such as long handled forceps, tongs, etc, while manipulating active sources from a distance of 15 to 100 cm. In its simplest form the long handled tongs will have a pistol grip together with a trigger mechanism operating a ‘ grip ’ which may be used to hold ‘the active source. An additional improvement over the latter one is the provision of a threaded screw which may be screwed up so that the grip remains securely fastened to the radioactive source. Drip trays of stainless steel or plastic, lined with absorbent paper, help to minimize the spread of contamination in case of spills. The tray should be without rough surfaces, or sharp corners, to facilitate easy decontamination. For higher levels of gamma activity, adequate shielding should be provided for containers of active materials and as far as possible incorporate necessary shielding close to the source. All manipulation should be done in a drip tray or in some form of double containers.

12.2 Pipetting of solutions and operations of wash bottles should never be performed by mouth, but by means of compression bulbs, remote handling pipettes, squeeze type wash bottles, etc. Never look down into a beaker or test-tube containing several millicuries of a strong beta emitter. Glassblowing on contaminated apparatus shall be done with techniques which do not involve mouth operation.

12.3 Placards bearing radiation symbols are required in the laboratory. The placards should also bear health safety instructions and should be put up, wherever radioactive sources are being manipulated or stored.

12.4 Equipment used for handling radioactive materials should be confined to the active area of laboratory.

12.5 Protective Clothing - In any radioisotope laboratory, the type of protective clothing required will depend upon the nature of work. For usual laboratory work (Type C) the ordinary laboratory coats are quite adequate. If work involves decontamination of equipment, a change of shoes in addition is advisable. Overshoes made of plastic or rubber material may be used.

12.6 Work shall not be carried out with radioactive materials or materials suspected to be carrying contamination without wearing rubber gloves. Rubber gloves used for handling active materials should not be used for handling other items, even in the active laboratory. Contaminated gloves should be thoroughly washed before taking off. The wearing and removal of the gloves should be in the same way as that of the surgical technique to minimize the contamination of hands. It is necessary to point out here, that while these gloves might provide adequate protection against soft beta rays, they are not adequate against hard beta rays. Heavier rubber gloves are more robust and give some measure of protection against beta radiation; they may be made more comfortable to wear by lining with cotton fabric.

12.7 Respirators -When the concentration of air-borne activity in working atmosphere goes above the maximum permissible levels during any major or minor operation, special precautions have to be taken. These include the wearing of a fully impervious clothing made up of a full rubber suit with boots, gloves and helmet and fresh air is supplied through an airline. Before donning such a wear, a full change of clothing is recommended. However, where the contamination level is not so high and is only occasional, lighter type of suit made of thin plastic material may be used with a simple airline hood. During short periods of emergency a high efficiency respirator is used along with a hood to cover the head. The body as a whole is covered with plastic overalls. In a radioisotope laboratory an accident, such as even a spillage might warrant use of respirators and protective apparel.

12.8 It is necessary to ensure the periodic check-up of handling equipment and examination at frequent intervals of respirators and protective clothing. This would help in keeping them ready for any emergency work.

13. HAZARD CHARACTERISTICS OF SOME COMMON RADIONUCLIDES

13.1 The radiation and hazard characteristics of some commonly used radionuclides are given in Appendix B. All values of ALI quoted are for occupational exposure only.

APPENDIX A
(***Clause 5.1***)

Classification of radioisotopes according to relative radiotoxicity per unit activity

Group I: Very High radiotoxicity

^{210}Pb	^{210}Po	^{223}Ra	^{226}Ra	^{228}Ra	^{227}AC	^{227}Th	^{228}Th	^{230}Th	^{231}Pa
^{230}U	^{232}U	^{233}U	^{234}U	^{237}Np	^{238} Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu
^{241}Am	^{243}Am	^{242}Cm	^{243}Cm	^{244}Cm	^{245}Cm	^{246}Cm	^{249}Cf	^{250}Cf	^{252}Cf

Group II: High radiotoxicity

^{22}Na	^{36}Cl	^{45}Ca	^{46}Sc	^{54}Mn	^{56}Co	^{60}Co	^{89} Sr	^{90}Sr	^{91}Y
^{95} Zr	^{106}Ru	^{1IO}Ag$_{m}$	^{115}Cd$_{m}$	^{114}In$_{m}$	^{124}Sb	^{125}Sb	^{127}Te$_{m}$	^{129}Te$_{m}$	^{124}I
^{126}I	^{131}I	^{133}I	^{134}Cs	^{137}Cs	^{140}Ba	^{144}Ce	^{152}Eu	^{154}Eu	^{160}Tb
^{170}Tm	^{181} Hf	^{182}Ta	^{192}Ir	^{204}Tl	^{207}Bi	^{210} Bi	^{211}At	^{212}Pb	^{224}Ra
^{228} AC	^{230}Pa	^{234}Th	^{236}U	^{249}Bk					

Group III: Moderate radiotoxicity

^{7}Be	^{14}C	^{18}F	^{24}Na	^{38}Cl	^{31}Si	^{32}P	^{35}S	^{41}A	^{42}K
^{43}K	^{47}Ca	^{47}Sc	^{48}Sc	^{48}V	^{51}Cr	^{52}Mn	^{56}Mn	^{52}Fe	^{55}Fe
^{59}Fe	^{57}Co	^{58}Co	^{63}Ni	^{65}Ni	^{64}Cu	^{65}Zn	^{69}Zn$_{m}$	^{72}Ga	^{73}As
^{74} As	^{76}As	^{77}As	^{75}Se	^{82}Br	^{85}Kr$_{m}$	^{87}Kr	^{86}Rb	^{85}Sr	^{91}Sr
^{90}Y	^{92}Y	^{93}Y	^{97}Zr	^{93}Nb$_{m}$	^{95}Nb	^{99}Mo	^{96}Tc	^{97}Tc$_{m}$	^{97}Tc
^{99}Tc	^{97}Ru	^{103}Ru	^{105}Ru	^{105}Rh	^{103}Pd	^{109} Pd	^{105}Ag	^{111}Ag	^{109}Cd
^{115}Cd	^{115}In$_{m}$	^{113}Sn	^{125}Sn	^{122}Sb	^{125}Te$_{m}$	^{127}Te	^{129}Te	^{13I} Te$_{m}$	^{132}Te
^{130}I	^{132}I	^{134}I	^{135}I	^{135}Xe	^{131}Cs	^{136}Cs	^{131}Ba	^{140}La	^{141}Ce
^{143}Ce	^{142}Pr	^{143}Pr	^{147}Nd	^{149}Nd	^{147}Pm	^{149}Pm	^{151}Sm	^{153} Sm	^{152}Eu
^{155}Eu	^{153} Gd	^{159}Gd	^{165}Dy	^{166}Dy	^{166}Ho	^{I69}Er	^{171}Er	^{171}Tm	^{175}Yb
^{177}Lu	^{181}W	^{185}W	^{187}W	^{183}Re	^{186}Re	^{188}Re	^{185}Os	^{191}Os	^{193}Os
^{190}Ir	^{194} Ir	^{191}P t	^{I93}Pt	^{197}Pt	^{196}Au	^{198}Au	^{199} Au	^{197}Hg	^{197}Hg$_{m}$
^{203}Hg	^{200}Tl	^{201}Tl	^{202}Tl	^{203}Pb	^{206}Bi	^{212}Bi	^{220}Rn	^{222}Rn	^{231}Th

^{233}Pa ^{239}Np

Group IV: Low radiotoxicity

^{3}H ^{15}O ^{37}A ^{58}Co$_{m}$ ^{59}Ni ^{69}Zn ^{71}Ge ^{85}Kr ^{85}Sr$_{m}$ ^{87}Rb
^{91}Y$_{m}$ ^{93}Zr ^{97}Nb ^{96}Tc$_{m}$ ^{99}Tc$_{m}$ ^{103}Rh$_{m}$ ^{I13}In$_{m}$ ^{129}I ^{13I} Xe$_{m}$ ^{133}Xe
^{134}Cs$_{m}$ ^{135}Cs ^{147}Sm ^{187}Re ^{19I} Os$_{m}$ ^{193}Pt$_{m}$ ^{197}Pt$_{m}$ ^{232}Th ^{Nat}Th ^{235}U
^{238}U ^{Nat}U

APPENDIX B
(clause 13.1)

HAZARD CHARACTERISTICS OF SOME RADIONUCLIDES

B-I. BARIUM 140 ($_{56}$Ba^{140})

Occurrence or production: A fission product (parent of La-140).

Production Process	Activation Cross-Section	Other Activities
U(n, f) Ba-140	_____	La-I40 (daughter) 40.2 h

Radioactive emission	Beta:	0.48 Mev (40 percent) I.02 Mev (60 percent)
	Gamma:	0.03 Mev*, 0.16 Mev, 0.30 Mev, 0.54 Mev*

(La^{140} activity always present)

Critical organ: Bone

Physical Half-Life	Biological Half-Life	Effective Half-Life
12.8 d	65 d	10.7 d

Hazard characteristics: K Factor (Ba - 140 + La- 140) 15 r/h at 1 cm/mCi.

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
F	2 x 10^{7} Bq	1 x 10^{7} Bq	0.100	8 x 10^{6} Bq

F, M & S – Default lung absorption types Fast, Moderate and Slow
f_1 – gut transfer factors ie proportion of the intake transferred to body fluids in the gut

*Most abundant gammas.

B-2. BERYLIUM 7 ($_4Be^7$)

Occurrence or production: Cyclotron production; cosmic ray production.

Production Process	Activation Cross-Section	Other Activities
C^{12} (p3, p3n) Be^7	__________	Not known
Li^7 (p, n) Be^7	0.51 b	

Radioactive emission	Gamma: 0.48 Mev (approximately 12 percent) EC*: 100 percent

Critical organ: Total body

Physical Half- Life	Biological Half- Life	Effective Half- Life
53.6 d	180 d	41 d

Hazard characteristics: K Factor 0.3 r/h at 1 cm/mCi.

Annual Limit on Intake (ALI)

	Inhalation 1 µm	5 µm	f_1	ingestion
M	4 x 10^8 Bq	5 x 10^8 Bq	0.005	7x 10^8 Bq
S	4 x 10^8 Bq	4 x 10^8 Bq		

B-3. BROMINE 82 ($_{35}Br^{82}$)

Occurrence or production: Irradiation of ammonium bromide and potassium bromide.

Production Process	Activation Cross-Section	Other Activities
Br^{81}(n, γ) Br^{82}	3.1 barns	Br^{80m} Br^{80} C^{l4}

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*Emits characteristic Li X-rays 0.052 Kev.

Radioactive emission	Beta:	0.44 Mev (100 percent)
	Gamma:	0.55 Mev (70 percent) 062 Mev (43 percent) 0.70 Mev (29 percent) 0.78 Mev (87 percent) 0.83 Mev (26 percent) I.04 Mev (30 percent) 1.32 Mev (28 percent) I.48 Mev (18 percent)

Critical organ: Total body

Physical Half- Life	Biological Half- Life	Effective Half- Life
1.5 d	8d	1.3 d

Hazard characteristics: K Factor 14.7 r/h at 1 cm/mCi.

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
F	$5x\ 10^7$ Bq	3×10^7 Bq	1.0	$4x\ 10^7$ Bq
M	3×10^7 Bq	2×10^7 Bq		

B-4. CAESIUM 137 ($_{35}Cs^{137}$)

Occurrence or production: A fission product.

Production Process	Activation Cross-Section	Other Activities
U (n, f) Cs^{137}	————	Cs^{134}

Radioactive emission	Beta:	0.61 Mev (92 percent) 1.17 Mev (8 percent)
	Gamma:	0.662 Mev (82 percent via 2.6 min $Ba^{137}m$)
	IC:	10 percent (characteristic Ba X-rays 32 Kev)

Critical organ: Total body

Physical Half- Life	Biological Half- Life	Effective Half- Life
1.1×10^4 d	70 d	70 d

Hazard characteristics: K Factor 3.1 r/h at 1 cm/mCi.

Annual Limit on Intake (ALI)

	Inhalation		ingestion	
	1 µm	5 µm	f_1	
F	4×10^6 Bq	3×10^6 Bq	1.0	1.5×10^6 Bq

B-5. CALCIUM 45 ($_{20}Ca^{45}$)

Occurrence or production: Reactor irradiation of $CaCO_3$

Production Process	Activation Cross-Section	Other Activities
Ca^{44} (n, γ) Ca^{45}	0.67 barns	Ca^{47} Ca^{49} Sc^{47} Sc^{49}

Radioactive emission: Beta: 0.25 Mev

Critical Organ: Bone

Physical Half-Life	Biological Half- Life	Effective Half- Life
164 d	1.80 x 104 d	162 d

Annual Limit on Intake (ALI)

	Inhalation		ingestion	
	1 µm	5 µm	f_1	
M	7×10^6 Bq	9×10^6 Bq	0.3	3×10^7 Bq

B-6. CARBON 14 ($_6C^{14}$)

Occurrence or production: Reactor irradiation of aluminium nitride.

Production Process	Activation Cross-Section	Other Activities
N^{14} (n, p) C^{14}	1.75 barns	Negligible

Radioactive emission: Beta: 0.155 Mev

Critical organ: Fat

Physical Half Life	Biological Half- Life	Effective Half- Life
2×10^6d	12 d	12d

Annual Limit on Intake (ALI)

	Ingestion
f_1 1.0	3×10^7 Bq

B-7. CHROMIUM 51 ($_{24}Cr^{51}$)

Occurrence or production: Reactor irradiation of chromium or potassium chromate.

Production Process	Activation Cross-Section	Other Activities
Cr^{50} (n,γ) Cr^{51}	13.5 barns	K^{42}

Radioactive emission	EC (100 percent) emits characteristic V X-ray of 5 Kev, Gamma: 0.323 Mev (approximately 8 percent)

Critical organ: Total body

Physical Half- Life	Biological Half- Life	Effective Half-Life
27.8 d	616 d	26.6 d

Hazard characteristics: K Factor 0.18 r/h at 1 cm/mCi
Annual Limit on Intake (ALI)

	Inhalation		ingestion	
	1 µm	5 µm	f_1	
F	1×10^9 Bq	7×10^8 Bq	0.1	5×10^8 Bq
M	6×10^8 Bq	6×10^8 Bq	0.01	5×10^8 Bq
S	6×10^8 Bq			

B-8. COBALT 60 ($_{27}Co^{60}$)

Occurrence or production: Reactor irradiation of cobalt or cobalt chloride in a reactor.

Production Process	Activation Cross-Section	Other Activities
Co^{59} (n, γ) Co^{60}	36.30 barns	Co^{60m}

Radioactive	Beta:	0.306 Mev (100 percent)

emission		1.48 Mev (approximately 0.15 percent)
	Gamma:	I.17 Mev (100 percent)
		1.33 Mev (100 percent)

Critical organ: Total body

Physical Half Life	Biological Half- Life	Effective Half- Life
1.9 x 10^3 d	9.5 d	9.5 d

Hazard characteristics: K Factor 13.0 r/h at 1 cm/mCi.

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
M	2x 10^6 Bq	3 x 10^6 Bq	0.1	6x 10^6 Bq
S	7 x 10^5 Bq	1 x 10^6 Bq	0.05	8x 10^6 Bq

B-9. GOLD 198 ($_{79}Au^{198}$)

Occurrence or production: Reactor irradiation of gold.

Production Process	Activation Cross-Section	Other Activities
Au^{197} (n, γ) Au^{198}	96 barns	Au^{199}

Radioactive emission	Beta:	0.29 Mev (1 percent)
		0.96 Mev (99 percent)
		1.37 Mev (0.025 percent)
	Gamma:	0.41 Mev (96.1 percent)
		0.68 Mev (1.1 percent)
		1.09 Mev (0.26 percent)
	IC:	3.6 percent

Critical organ: Kidney

Physical Half- Life	Biological Half- Life	Effective Half- Life
2.7 d	280 d	2.7 d

Hazard characteristics: K Factor 2.3 r/h at 1 cm/mCi,

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
F	9x 10^7 Bq	5 x 10^7 Bq	0.1	2x 10^7 Bq
M	3 x 10^7 Bq	2 x 10^7 Bq		

S	2x 10^7 Bq	2 x 10^7 Bq

B-10. IODINE 131 ($_{53}I^{131}$)

Occurrence or production: Iodine-131 is obtained by the irradiation of Te-130 in a reactor as also in the products of nuclear fission of uranium.

Production Process	Activation cross-section	Other Activities
Te^{130} (n, γ) $Te^{131m} \xrightarrow[\beta]{} I^{131}$	0.22 barns	Te-121m Te-123 Te-125 (Te-127m) (Te-129) Xe-131m Te-I31m (30 h)

Radioactive emission	Beta:	0.25 Mev (3 percent)
		0.33 Mev (9 percent)
		0.61 Mev (87 percent)
		0.81 Mev (1 percent)
	Gamma:	0.08 Mev (2 percent)
		0.28 Mev (5 percent)
		0.36 Mev (80 percent)
		0.64 Mev (9 percent)
		0.72 Mev (3 percent)
	IC:	4 percent

Critical organ: Thyroid

Physical Half- Life	Biological Half- Life	Effective Half- Life
8.0 d	138 d	7.6 d

Hazard characteristics: K Factor 2.18 r/h at 1 cm/mCi.

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
F	3x 10^6 Bq	2 x 10^6 Bq	0.1	9x 10^5 Bq

B-11. IRON 59 ($_{26}Fe^{59}$)

Occurrence or production: Reactor irradiation of iron or Fe_2O_3 leads to the formation of iron-59.

Production Process	ActivationCross-Section	Other Activities

Fe-58 (n, γ) Fe-59	0.98 barns	Fe^{58}

Radioactive emission	Beta:	0.27 Mev (46 percent) 0.46 Mev (54 percent) I.56 Mev(0.3 percent)
	Gamma:	0.1919 Mev (2.5 percent) I.10 Mev (56 percent) I.29 Mev (44 percent)

Critical organ : Spleen

Physical Half- Life	Biological Half- Life	Effective Half- Life
45.1 d	600 d	41.9 d

Hazard characteristics : K Factor 6.2 r/h at 1 cm/mCi.

Annual Limit on Intake (ALI)

	Inhalation		ingestion	
	1 µm	5 µm	f_1	
F	9x 10^6 Bq	7x 10^6 Bq	0.1	1x 10^7 Bq
M	6x 10^6 Bq	6 x 10^6Bq		

B-12. PHOSPHORUS 32 ($_{15}P^{32}$)

Occurrence or production: Produced in reactors by irradiation of red phosphorus or KH_2PO_4

Production Process	Activation Cross-Section	Other Activities
P^{31} (n, γ) P^{32}	0.19 barns	K^{42}
S^{32} (n, p) P^{32}	-	p^{33} s^{35} s^{37}

Radioactive emission	Beta:	1.71 Mev

Critical organ: Bone

Physical Half- Life	Biological Half- Life	Effective Half- Life

14.3 d	1.155 d	14.1 d

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
F	3x 10^7 Bq	2x 10^7 Bq	0.8	8x 10^6 Bq
M	6x 10^6 Bq	7 x 10^6Bq		

B-13. PLUTONIUM 239 ($_{94}Pu^{239}$)

Occurrence or production: The target is not a specified one. Various chemical forms of uranium may be employed.

Production Process	Activation Cross-Section	Other Activities
U^{238} (n, γ) $U^{239} \xrightarrow[23.5m]{\beta} Np^{239} \xrightarrow[2.3d]{\beta} Pu^{239}$	2.74 barns	Not known

Radioactive Emission	Alpha:	5.09 Mev (10.7 percent) 5.13 Mev (16.8 percent) 5.14 Mev (72.5 percent)

Critical organ: Bone

Physical Half- Life	Biological Half- Life	Effective Half-Life
8.9 x 10^6 d	7.3 x 10^4 d	7.2 x 10^4 d

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
M	4x 10^2 Bq	6x 10^2 Bq	5.0 x 10^{-4}	8x 10^4 Bq
S	1 x 10^3 Bq	2 x 10^3Bq	1.0 x $10^{-}5$	2x 10^6 Bq

B-14. POLONIUM 210 ($_{84}Po^{210}$ RaF)

Occurrence or production: Reactor irradiation of bismuth oxide leads to the formation of polonium-210.

Production Process	Activation Cross-Section	Other Activities
Bi^{209} (n, γ) $Bi^{210} \longrightarrow Po^{210}$	0.0 19 barns	None

(5d) β

Radioactive	Alpha:	5.305 Mev (100 percent)
Emission	Gamma:	0.8 Mev (0.001 2 percent)

Critical organ: Spleen

Physical Half- Life	Biological Half-Life	Effective Half- Life
138.4 d	60 d	42 d

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
F	3x 10^4 Bq	3x 10^4 Bq	0.1	8x 10^4 Bq
M	7 x 10^3 Bq	9x 10^3Bq		

B-15. POTASSIUM 42 ($_{19}K^{42}$)

Occurrence or production: Reactor irradiation of potassium carbonate or potassium chloride in a reactor.

Production Process	Activation Cross-Section	Other Activities
K^{41} (n, γ) K^{42}	1.1 barns	p^{32} S^{35} Cl^{36} Cl^{38}

Radioactive	Beta:	2.0 Mev (18 percent)
emission		3.6 Mev (82 percent)
	Gamma:	1.53 Mev (18 percent)

Critical organ: Total body

Physical Half- Life	Biological Half- Life	Effective Half- Life
0.52 d	58 d	0.52 d

Hazard characteristics: K Factor 1.37 r/h at 1 cm/mCi.

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
F	2 x 10^8 Bq	1 x 10^8 Bq	1.0	5 x 10^7 Bq

B-16. RADIUM 226 ($_{88}Ra^{226}$)

Occurrence or production: It is a naturally occurring radioisotope available in significant quantities in pitchblende.

Production Process	Activation Cross-Section	Other Activities
Natural radioisotope	———	Daughter products of the U-Ra series

Radioactive Emission	Alpha:	4.589 (5.7 percent) 4.777 (94.3 percent)
	Gamma:	0.188 (approximately 4 percent)
	IC:	2 percent
	Activity due to Radon and daughters present	

Critical organ: Bone

Physical Half- Life	Biological Half-Life	Effective Half-Life
5.9 x $I0^{5}$ d	1.64 x $I0^{4}$ d	1.64 x $I0^{4}$ d

Hazard characteristics: K Factor 8.25 r/h at 1 cm/mCi.

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
M	6 x 10^{6} Bq	9 x 10^{3} Bq	0.2	7 x 10^{4} Bq

B-17. SILVER 110 m ($_{47}Ag^{110m}$)

Occurrence or production: Irradiation of silver in a reactor leads to the formation of Ag-110.

Production Process	Activation Cross-Section	Other Activities
Ag^{109} (n, γ) Ag^{110m}	3.2 barns	None

Radioactive emission	Beta:	0.087 Mev (55 percent) 0.53 Mev (43 percent) 2.87 Mev (2 percent via 24 sec Ag-110)
	Gamma:	0.66 Mev (94 percent) 0.68 Mev (12 percent) 0.71 Mev (17 percent)

0.74 Mev (5 percent)
0.76 Mev (21 percent)
0.81 Mev (8 percent)
0.88 Mev (69 percent)
0.94 Mev (29 percent)
1.38 Mev (26 percent)
1.48 Mev (5 percent)
1.51 Mev (14 percent)
IT: [0.116 Mev (approximately 0 percent)]
(IC : 2 percent to 24 sec Ag-110)

Critical organ: Kidney

Physical Half- Life	Biological Half-Life	Effective Half- Life
270 d	10 d	10 d

Hazard characteristics: Nil.

Annual Limit on Intake (ALI)

	Inhalation		ingestion	
	1 µm	5 µm	f_1	
F	4x 10^6 Bq	3x 10^6 Bq	0.05	7x 10^6 Bq
M	3 x 10^6 Bq	3 x 10^6Bq		
S	2 x 10^6 Bq	3 x 10^6Bq		

B-18. SODIUM 24 ($_{11}Na^{24}$)

Occurrence or production: Reactor irradiation of sodium carbonate, sodium chloride or sodium bicarbonate yields sodium-24

Production Process	Activation Cross-Section	Other Activities
Na^{23} (n, γ) Na^{24}	0.536 barns	Cl^{36} Cl^{38} P^{32} S^{35}

Radioactive emission	Beta:	1.39 Mev (100 percent)
	Gamma:	1.37 Mev (100 percent) 2.76 Mev (100 percent)

Critical organ: Total body

Maximum permissible body burden: 7 µCi

Physical Half-Life	Biological Half-Life	Effective Half- Life
0.63 d	11d	0.6d

Hazard characteristics : K Factor 18.4 r/h at 1 cm/mlCi.

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
F	7x 10^7 Bq	4x 10^7 Bq	1.0	5x 10^7 Bq

B-19. STRONTIUM 90 ($_{38}Sr^{90}$)

Occurrence or production: Strontium-90 is a fission product.

Production Process	Activation Cross-Section	Other Activities
U (n, f) Sr^{90}	————	Sr^{89} Y^{90}

Radioactive emission	Beta: 0.54 Mev Y^{90} -β 2.26 Mev

Critical organ: Bone

Physical Half- Life	Biological Half-Life	Effective Half-Life
10^4 d	1.8 x 10^4 d	6.4 x 10^3 d

Hazard characteristics: Mostly in equilibrium with Y^{90} (T- I/2 64.4 h - Mev β 2.2).

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
F	8x 10^5 Bq	7x 10^5 Bq	0.3	7x 10^5 Bq
S	1x 10^5 Bq	3x 10^5 Bq	0.01	7x 10^6 Bq

B-20. SULPHUR 35 ($_{16}S^{35}$)

Occurrence or production: Obtained by irradiation of sulphur or potassium chloride in a reactor.

Production Process	Activation Cross-Section	Other Activities
S^{34} (n, γ) S^{35}	0.26 barns	P^{32} S^{37}

Cl^{35} (n, p) S^{35}	0.19 barns	Cl^{38} p^{32} Na^{24}

Radioactive emission Beta: 0.167 Mev

Critical organ: Testis

Physical Half- Life	Biological Half- Life	Effective Half-Life
87.1 d	623 d	76.4 d

Annual Limit on Intake (ALI)

		Inhalation		ingestion	
		1 µm	5 µm	f_1	
Inorganic	F	4x 10^8 Bq	3x 10^8 Bq	0.8	1x 10^8 Bq
	M	2x 10^7 Bq	2x 10^7 Bq	0.1	1x 10^8 Bq
Organic				1.0	3x 10^7 Bq

B-21. THORIUM 232, NATURAL

Occurrence or production: This is a naturally occurring radioisotope abundantly available in monazite.

Production Process	Activation Cross-Section	Other Activities
Natural radioisotope	———————	MsThI (Ra^{228}) and daughter

Radioactive emission Alpha: 4.007 Mev (100 percent)
MsThII (Ac^{228}) 6.13 h
IC:24 percent

Critical organ: Bone

Physical Half-Life(Th^{232})	Biological Half-Life	Effective Half- Life
5.1 x 10^{12} d	7.3 x 10^4 d	7.3 x 10^4 d

Annual Limit on Intake (ALI)

	Inhalation		ingestion	
	1 µm	5 µm	f_1	
M	5x 10^2 Bq	7x 10^2 Bq	5.0 x 10^{-4}	9x 10^4 Bq
S	9x 10^2 Bq	2x 10^3 Bq	2.0 x 10^{-4}	2x 10^5 Bq

B-22. TRITIUM ($1H^3$)

Occurrence or production: Activation of lithium leads to the formation of tritium.

Production Process	***Activation Cross-Section***	***Other Activities***
Li^6 (n, α) H^3	0.028 barns	None

Radioactive emission	Beta: 0.018 Mev

Critical organ: (HTO or $H^3_2 0$) body tissue

Physical Half- Life	Biological Half- Life	Effective Half- Life
4.5×10^3 d	12 d	12 d

*Annual Limit on Intake (*ALI)

Inhalation	*ingestion*	
1 µm	f_1	
1×10^9 Bq	1.0	1×10^9 Bq

B-23. URANIUM, NATURAL

Occurrence or production: Occurs naturally

Production Process	Activation Cross-Section	Other Activities
Natural radioisotope	__________	Decay products
U^{238} (99.24 percent)	__________	________
U^{235} (0.071 4 percent)	__________	__________
U^{234} (0.040 percent)	___________	__________

Radioactive Emission	Alpha: 4.2 Mev (100 percent) IC: 23 percent

Critical organ: Kidney

Physical Half- Life (U^{238})	Biological Half-Life	Effective Half-Life
1.6×10^{12} d	15 d	15 d

Annual Limit on Intake (ALI)

	Inhalation 1 µm	5 µm	ingestion f_1	
F	4×10^4 Bq	3×10^4 Bq	0.02	5×10^5 Bq

M	8x 10^3 Bq	1 x 10^4Bq	0.002	3 x 10^6 Bq
S	3 x 10^3 Bq	4 x 10^3Bq		

B-24. ZINC 65 ($_{30}Zn^{65}$)

Occurrence or production: Reactor irradiation of zinc leads to formation of zinc-65.

Production Process	Activation Cross-Section	Other Activities
Zn^{64} (n, γ) Zn^{65}	0.44 barns	Zn^{69} Zn^{69m}

Radioactive emission

EC Beta: EC (98.5 percent)
β+0.325 Mev (I.5 percent)
Gamma: I.1 1 Mev (45 percent)
Emits characteristics Cu X-rays 8.0 Kev
2.5 Mev gamma rays emitted when a positron is emitted.

Critical crgan: Total body

Physical Half- Life	Biological Half- Life	Effective Half- Life
245 d	933 d	194 d

Hazard characteristics: K Factor 2.7 r/h at 1 cm/mCi.

Annual Limit on Intake (ALI)

	Inhalation			ingestion
	1 µm	5 µm	f_1	
S	7x 10^6 Bq	7x 10^6 Bq	0.5	5x 10^6 Bq

B-25. ZIRCONIUM 95 ($_{40}Zr^{95}$)

Occurrence or production: Reactor irradiation of zirconium dioxide in a reactor yields Zr-95 besides occurring in the fission products.

Production Process	Activation Cross-Section	Other Activities
Zr^{94}(n, γ) Zr^{95}	0.09 barns	Zr^{97} Nb^{97} Nb^{95} daughter Hf ^{175} Hf ^{l8l} (from impurities)

Radioactive Emission

Beta: 0.360 Mev (approximately 43 percent)
0.40 Mev (approximately 35 percent)
0.88 Mev (2 percent)
Gamma: 0.72 Mev (approximately 55 percent)
0.75 Mev (approximately 48 percent)

0.23 Mev (0 percent via 90 h Nb-95m)
IC: 2 percent

Critical organ: Total body

Physical Half- Life	Biological Half- Life	Effective Half- Life
63.3 d	450 d	55.5 d

Annual Limit on Intake (ALI)

	Inhalation		ingestion	
	1 µm	5 µm	f_1	
F	8x 10^6 Bq	7x 10^6 Bq	0.002	2x 10^7 Bq
M	4x 10^6 Bq	6 x 10^6 Bq		
S	4 x 10^6 Bq	5 x 10^6 Bq		