GOVERNMENT OF INDIA

AERB SAFETY GUIDE

MEDICAL MANAGEMENT OF PERSONS EXPOSED IN RADIATION ACCIDENTS

ATOMIC ENERGY REGULATORY BOARD

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Guide on Medical Management of Persons Exposed in Radiation Accidents

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FOREWORD

To meet the growing need for electric power in the country, the Government of India has planned to increase the installed nuclear power generation capacity to 10,000 MWe by the turn of the century. It is planned to augment the associated fuel cycle facilities correspondingly. We have achieved a commendable self-sufficiency in radioisotope production and success in development of their applications in medicine, industry, agriculture & food and other fields. In view of the multiplier effects of these applications on our economy, health care and the safety and quality of our industrial products, one may visualize an increased scale and variety of radiation applications in our country in the years to come.

Extreme care is taken to ensure radiation safety in all these applications of nuclear technology by a regulatory programme which encompasses availability of trained personnel, properly designed installations with engineered safety features, and adoption of safe operating procedures. While we may justifiably be proud of our safety record in comparison with several countries where nuclear technology has been introduced on a large scale, we should have proper emergency response plans to cope with any radiation accidents, including the medical management of persons involved in such accidents.

The Atomic Energy Regulatory Board has prepared a guide on this subject. The guide was prepared by a committee consisting of the following members from the Atomic Energy Regulatory Board (AERB) and the Bhabha Atomic Research Centre (BARC) :

Shri S. Somasundaram (Chairman)	-	Radiation Safety Division, AERB.
Dr. G.K. Iyer	-	Medical Division, BARC.
Dr. P.S. Iyer	-	Division of Radiological Protection, BARC.
Shri S. Krishnamony	-	Health Physics Division, BARC.
Dr. B.J. Shankar	-	Medical Division, BARC.
Shri Masood Ahmad (Member-Secretary)	-	Radiation Safety Division, AERB.

In addition, the following members were coopted by the main committee:-

Dr. S.H. Advani	-	Tata Memorial Hospital, Bombay
Shri V.B. Menon	-	Health Physics Division, BARC
Dr. B.S. Rao	-	Division of Radiological Protection, BARC

The draft of this guide was circulated amongst a large number of medical and radiation protection experts both within and outside the country and their comments and suggestions were taken into consideration while finalising the guide. The comments received from Drs. A. Barabanova and A. Gouskova (USSR), J.C. Nenot (France) and G.L. Voelz (USA) were especially useful.

It is hoped that this guide would provide a useful reference for medical and para-medical personnel as well as those responsible for emergency response planning in radiation installations.

SDSoman

(S.D. Soman)
Chairman,
Atomic Energy Regulatory Board

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CHAPTER 1

GENERAL CONSIDERATIONS

1.1 INTRODUCTION

Soon after independence, the Government of India set up the Department of Atomic Energy (DAE) to develop and promote the peaceful applications of nuclear technology. The country has made rapid progress and achieved self-reliance and self-sufficiency in this field. Nuclear power stations are already in operation at Tarapur (Maharashtra), Kota (Rajasthan) and Kalpakkam (Tamil Nadu). The first unit of Narora Atomic Power Project, (NAPP) in Uttar Pradesh has been commissioned and the second unit is expected to go critical during 1991. Work has commenced on similar units at Kakrapar (Gujarat), Kaiga (Karnataka) and units 3 & 4 at Rawatbhata. The nuclear power generation capacity in the country, based on Pressurised Heavy Water Reactors (PHWR), is expected to reach 10,000 (MWe) by the turn of the century. It is planned to set up two pressurised water reactors of VVER - 1000 design at Kudangulam in Tamilnadu. To support the nuclear power programme, DAE has established full-fledged nuclear fuel cycle facilities and R & D centres. The fuel cycle facilities encompass exploration of atomic minerals, mining, milling, fuel fabrication, heavy water production, fuel reprocessing and radioactive waste management. Fig. 1.1 shows the location of these facilities.

A large variety of radioisotopes in sealed and unsealed forms are produced in quantities ranging from a few millicuries to several kilocuries and are finding increasing application in industry, medicine, agriculture and research. These uses will diversify and expand further in the coming years. The major industrial applications include industrial radiography, sterilisation of medical supplies, wood polymerisation, food preservation and sewage treatment. Table 1.1 shows data on the distribution of industrial radiography cameras and large industrial irradiators in the country. In medicine, besides the diagnostic use of X-rays and radioisotopes, teletherapy and brachytherapy units incorporating sealed radioisotopes, high voltage X-ray machines and high energy accelerators are used for treatment of cancer. Radioisotopes in unsealed form are also used for treatment of malignant and benign diseases. Table 1.2 summarises data on medical applications of radiation in the country. Radioactive sources and nuclear fuels (fresh and spent) are transported by suitable means - air, rail, road and water transportation.

An estimated 33,000 persons employed as radiation workers - about 12,500 in DAE installations and about 20,500 persons in other organisations - are covered by the personnel monitoring programme of Division of Radiological Protection (DRP), BARC. The rate of growth of radiation workers is about 880 persons per year in DAE installations and about 650 persons per year in other organisations, based on 1980-1988 data.

1.2 RADIATION ACCIDENTS - INDIAN AND WORLDWIDE EXPERIENCE

1.2.1 INDIAN EXPERIENCE

The radiation safety record in the country has been good. About 25 accidents have been reported during the period 1980-1985, associated with ^{192}Ir and ^{60}Co industrial radiography sources. Fifty-six persons were exposed to radiation in these accidents, among them four persons received significantly high doses to the skin, leading to radiation burn which required medical treatment and surgical intervention. Eight incidents have been reported during the period 1967-1988 in medical applications. Six of these incidents were associated with teletherapy units; 24 persons received low radiation doses and one person received a high dose on hand, requiring amputation. Two incidents were associated with X-ray fluoroscopy, during cardiac catheterisation in one case and pacemaker insertion in the other; the two patients received very high doses to the skin of their back.

1.2.2 WORLD-WIDE EXPERIENCE

Detailed information is available on radiation accidents which have occurred in other countries. There have been three major accidents in nuclear power and plutonium production reactors - Windscale, UK (1957); Three Mile Island, USA (1979) and Chernobyl, USSR (1986). In the first two accidents there were no fatalities; in Chernobyl reactor accident 237 persons were hospitalised for acute radiation sickness and 29 persons died. During the period 1945-1988 thirteen nuclear criticality accidents have been reported from Argentina, Belgium, USA, USSR and Yogoslavia --3 in experimental critical assemblies, 6 in research reactors and 4 in chemical processing plants. 46 persons were exposed to radiation in these accidents and 9 persons died. Twenty eight incidents have been reported during the period

Fig. 1.1 Atomic Energy Establishments in India

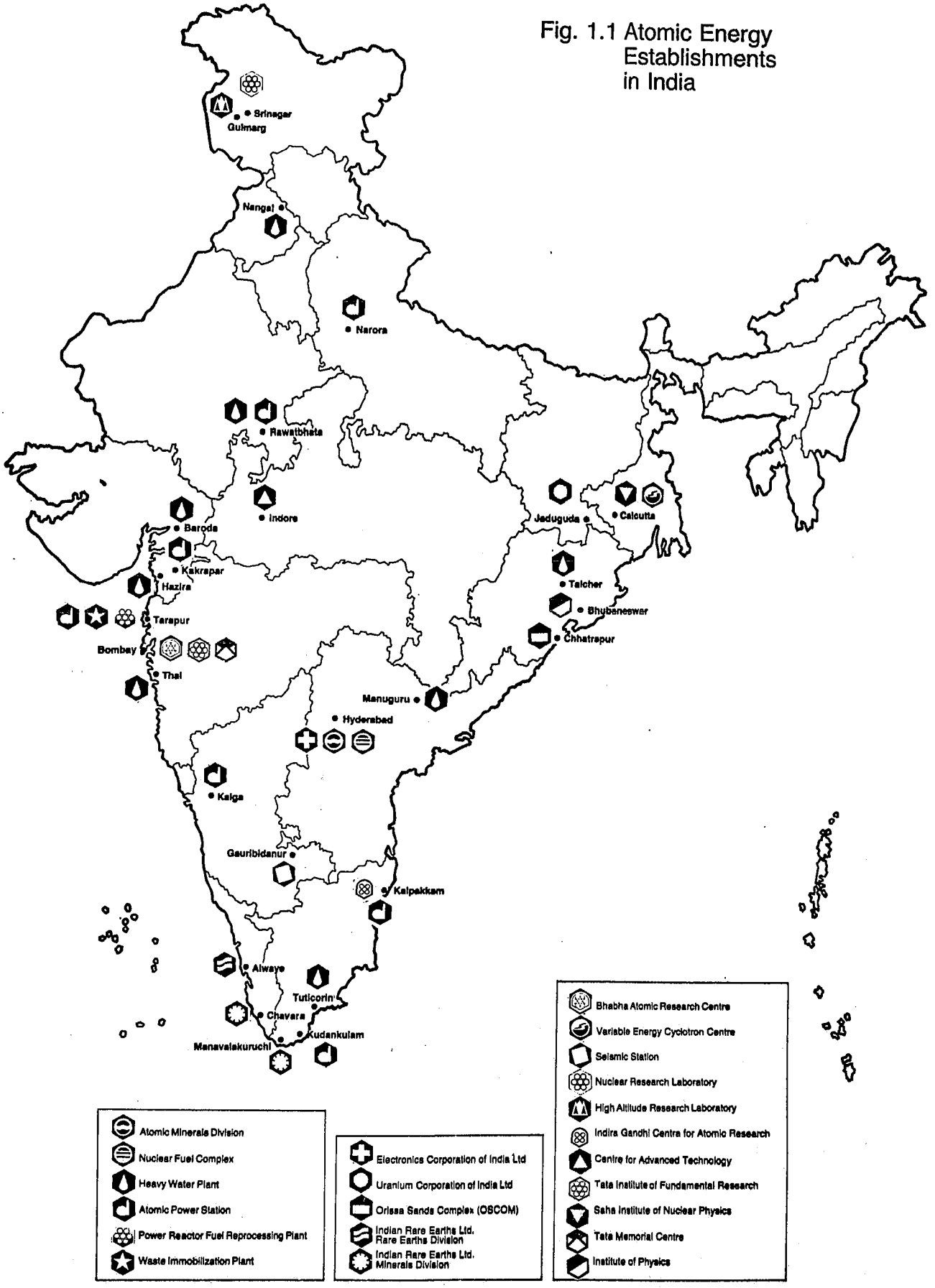


TABLE 1.1:DATA ON APPLICATIONS OF RADIATION IN INDUSTRIAL RADIOGRAPHY/IRRADIATION IN INDIA

A. Number of institutions, equipment and sites authorised

Region	Institutions	Radiography Equipment	Radiography Sites
Eastern	57	132	76
Northern	45	93	51
Southern	93	227	120
Western	121	390	183
Total	316	842	430

B. Personnel

Total number of site-in-charge personnel :	1656
Total number of certified radiographers :	1438

C. Equipment (Radiography)

Radiography cameras using ^{192}Ir upto a strength of 20 Ci (0.74 TBq)	567
Radiography cameras using ^{192}Ir of a strength of 50 Ci (1.8 TBq) (remotely operated)	180
Radiography equipment using ^{137}Cs upto 10 Ci (0.37 TBq)	9
Radiography equipment using ^{60}Co	
- 5-30 Ci (0.18 - 10.01 TBq)	84
- 1000 Ci (37 TBq)	3
Radiography equipment using X-rays	150
Radiography equipment using linear accelerators (X-rays)	3

D. ^{60}Co Irradiation equipment

Gamma shine units upto 1000 Ci (37 TBq)	2
Gamma cells/chambers upto 5000 Ci (185 TBq)	89
Gamma irradiators - upto 100,000 Ci (3.7 PBq)	6
Sterilisation plants-upto 1 MCi (37PBq)	3

TABLE 1.2 : DATA ON MEDICAL APPLICATIONS OF RADIATIONS IN INDIA

A. Estimated number of diagnostic X-ray machines	35,000
B. Nuclear Medicine-Diagnosis & Therapy	
Number of nuclear medicine centres	
- Minor	62
- Major	30
- Total	92
Number of gamma cameras	35
C. Brachytherapy	
Number of brachytherapy centres	85
Number of remote afterloading applicators	27
Number of tubes and needles (about)	2 000
- Amount of radium (estimate)	5g
- Amount of cobalt-60	3.0 Ci (111.0 GBq)
- Amount of cesium-137	4.0 Ci (148.0 GBq)
D. Beam therapy	
Number of teletherapy centres	98
Number of teletherapy units	
-Telegamma units	150
-Accelerators	9
-Treatment planning systems	20

TABLE 1.3 : SERIOUS RADIATION ACCIDENTS REPORTED (1945-1989)[2]

Type of facility	No.of events	Over exposures	Deaths
Nuclear facilities	27	272	35
Non-Nuclear facilities			
Industry	44	87	21
Research	7	10	-
Medical	4	62	4
	82	431	60

TABLE 1.4 : FATAL RADIATION ACCIDENTS REPORTED (1945-1989)[2]

Year	Location	Radiation Source	Fatalities@	
			Worker	Public
1945	Los Alamos, USA	Critical assembly	1	
1946	Los Alamos, USA	Critical assembly	1	
1958	Vinca, Yugoslavia	Experimental Reactor	1	
1958	Los Alamos, USA	Critical assembly	1	
1961	Switzerland	Tritiated paint	1	
1962	Mexico City,Mexico	Lost radiography source		4
1963	China	Seed irradiator		2
1964	Germany,FRG.	Tritiated paint	1	
1964	Rhode Island, USA	Uranium recovery plant	1	
1975	Brescia, Italy	Food irradiator	1	
1978	Algeria	Lost radiography source		1
1981	Oklahoma, USA	Industrial radiography	1	
1982	Norway	Instrument sterilizer	1	
1983	Constituyentes, Argentina	Research reactor	1	
1984	Morocco	Lost radiography source		8
1986	Chernobyl, USSR	Nuclear power plant	29	
1987	Goiania, Brazil	Teletherapy source		4
1989	San Salvador, El Salvador	Irradiator	1	
		Total	41	19

@In nuclear facilities and non-nuclear industry, research and medicine (excluding patient related events).

1954-1988 from Algeria, Argentina, Brazil, Bulgaria, China, France, Italy, Japan, Mexico, Morocco, Norway, South Africa, UK, USA and USSR, in which 64 persons received acute whole-body radiation from different sources such as ^{137}Cs teletherapy source, ^{192}Ir and ^{60}Co radiography sources, ^{60}Co industrial irradiators, Klystron and Van de Graaf accelerator; 22 persons died. During the period 1945-83, 171 cases of serious localised irradiation have been reported from several countries; 50 cases required surgical intervention. Three persons received radiation injuries in an industrial irradiation facility in El Salvador in 1989[1] and one of them died subsequently. Table 1.3 lists serious radiation accidents reported during 1935-1989. Table 1.4 shows the fatal radiation accidents reported during the same period.

From the above, it is clear that radiation accidents are comparatively infrequent. Apart from radiation workers, even members of the public may be inadvertently exposed to radiation - for example, a child or an unsuspecting person, picking up a lost radiography source pencil. Ionising radiations are not detected by our senses and in certain cases the exposed person may not be aware of his radiation exposure. There is often a latent period between radiation exposure and the manifestation of clinical symptoms; the smaller the dose, the longer is this latent period. The prodromal symptoms which persons develop after radiation exposure - e.g. nausea, vomiting and erythema are not specific to radiation and the examining general practitioner may attribute them to other, more familiar causes. If the radiation dose is low, the patient can recover from radiation illness spontaneously. However, for persons receiving radiation dose within a certain range, correct diagnosis and proper medical management can influence the outcome. These aspects should be kept in mind while planning and organising facilities for medical management of persons involved in radiation accidents.

1.3 CLASSIFICATION OF RADIATION ACCIDENTS

Accidents involving radiation sources and radioactive materials can be generally classified as those resulting in (a) external irradiation and (b) radioactive contamination. External irradiation can result in whole body exposure, partial body exposure or localised exposure of skin (radiation burn). Whole-body exposure occurs when the entire body is irradiated in uniform or non uniform manner. Partial body exposure occurs when a large part of the body is irradiated.

Radioactive contamination may be of two types (a) external or (b) internal. External contamination can occur as a result of spillage of radioactive material on skin or hands coming in contact with loose radioactive material. It can cause irradiation of the skin and underlying tissues as well as provide a potential for the material to enter the body subsequently. This possibility is high if the integrity of the skin is lost due to wounds, abrasions or chemicals.

Internal contamination occurs most often as a result of inhalation of radioactive materials in finely divided form. As mentioned above, it may also occur when contamination present on the skin penetrates the outer layer and enters systemic circulation. Internal contamination can also occur as a result of eating with contaminated hands or consuming contaminated water or food; such instances are, however, relatively uncommon.

It is important to note that the facilities and protocols for dealing with external irradiation (whole body, partial and localised) and radioactive contamination (external, internal or both) are somewhat different. In the case of external irradiation, first aid is not required unless it is accompanied by traumatic injury and there is usually time available for sending the exposed person for medical care to a hospital properly equipped to deal with such cases. Highly specialised facilities and procedures which are expensive and specially trained personnel are required, if the dose received by the person is around or exceeds the median lethal range $LD_{50(60)}$. In the case of radioactive contamination, there is usually no immediate risk to life. However, in order to minimise long-term sequelae in tissues or organs from biologically incorporated radioactive material, it is prudent to block or minimise systemic uptake and hasten the biological elimination of the contaminant. First aid, if administered to the person within a short period (generally within the first half-an-hour even in cases of suspected intake) at a place near the place of accident, is effective and usually adequate for this purpose.

1.4 POTENTIAL FOR DIFFERENT TYPES OF ACCIDENTS

Table 1.5 indicates the potential for different types of accidents, outlined above, in the operation of various nuclear fuel cycle facilities and in industrial and medical applications of radiation sources and radioisotopes. This information may be helpful in planning and organisation of facilities for medical management of different types of radiation accidents.

TABLE 1.5 : POTENTIAL FOR DIFFERENT CATEGORIES OF RADIATION EXPOSURE REQUIRING MEDICAL INTERVENTION

1. DAE FACILITIES

Facility	External Irradiation		Contamination		Remarks
	Acute whole body irradiation	Partial body irradiation and radiation burns	External	Internal	
1.Uranium mine	-	-	-	-	On account of low concentration of radioactivity in the ore, radiation accidents involving signifacant internal/external exposure are not likely.
2.Uranium mill		-	+	+	
3.Uranium refining and fuel fabrication plants	-	-	++	++	Internal exposure from inhalation of UF_6 is a special problem.
4. Plutonium fuel fabrication	+	+	++	++	External acute wholebody or partial body exposure from accidental criticality excursions.
5.Nuclear reactor	+	++	++	++	Internal exposures from ^{131}I and HTO are likely.
6. Irradiated fuel reprocessing plants	++	++	+++	+++	External whole body or partial body irradiation from gamma rays and neutrons, possible in the event of criticality accident. Radiation burns possible as a result of inadvertent handling of intensely radioactive sources and highly contaminated components. External irradiation from beta radiation likely in the event of close approach to sources such as spilled process solutions or fuel debris. Severe external contamination of skin/clothing likely as a result of spillage of corrosive or chemically reactive solutions containing high concentrations of fission products or plutonium; this can be accompanied by chemical burns. Internal exposure from inhalation of fission products and plutonium aerosols likely.
7. Radioisotope production	+	++	++	++	
8. Radio-active waste management					
-low level	-	-	+	+	
-High level	-	-	++	++	

(TABLE 1.5 CONTINUED)

Facility	External Irradiation		Contamination		Remarks
	Acute whole body irradiation	Partial body irradiation and radiation burns	External	Internal	
9.High energy particle accelerators		+	+	+	External exposure to fast neutrons and gammas, emitted by targets, can occur in accelerator vaults due to human error. External contamination can result during handling of irradiated targets especially transuranics. Internal contamination can result from transfer of external contamination.

2.INDUSTRIAL APPLICATIONS

Facility	External Irradiation		Contamination		Remarks
	Acute whole body irradiation	Partial body irradiation and radiation burns	External	Internal	
1. Industrial radiography	-	+	-	-	Commonly used sources are ^{192}Ir and ^{60}Co. Radiation burns and/or partial body irradiation can occur if hands/parts of body are directly exposed to beam or if sources are handled or picked up by hand.
2. Industrial irradiators	+	-	-	-	
3. Nucleonic guages	-	+	-	-	
4. Radiotracers	-	+	+		

3. MEDICAL APPLICATIONS

Facility	External Irradiation		Contamination		Remarks
	Acute whole body irradiation	Partial body irradiation and radiation burns	External	Internal	
1. Diagnostic	-	+	-	-	Direct exposure to beam can cause irradiation/ radiation burns.
2. Radio-therapy:					
Teletherapy	-	+	-	-	Direct exposure to source can result in severe partial body irradiation or radiation burns.
Brachytherapy	-	++	+	-	Broken or lost sources can cause irradiation;
3. Nuclear Medicine	-	-	+	+	Mostly short-lived nuclides are used. Of special importance is ^{131}I in therapeutic doses.

Note :
+++ indicates high potential
++ indicates moderate potential
+ indicates low potential
- indicates not applicable.

1.5 PLANNING AND ORGANISATION OF MEDICAL FACILITIES

The considerations discussed above suggest organisation of medical facilities at four levels, as given in Table 1.6

TABLE 1.6 : LEVELS OF MEDICAL FACILITIES

Medical Facility	Function
A. First-aid Post	-Simple cases of external decontamination. -Blocking/minimising systemic uptake in cases of internal contamination, including suspected intakes. -Preliminary screening of persons in cases of external irradiation.
B. Personnel Decontamination Centre	-Treatment of persistent and difficult cases of external contamination, including those accompanied by traumatic injury. - Internal decontamination, including minor surgery where required.
C. Site Hospital	- Medical management of cases of radioactive contamination accompanied by life-threatening injuries. - Treatment of cases of localised and partial body irradiation. - Medical management of cases receiving low doses of whole-body external radiation. - Medical management of cases receiving median-lethal low doses of whole-body external radiation,prior to transfer to specialised centre. -Terminal care of cases receiving extremely high doses of whole-body external radiation.
D. Specialised Centre	-Medical management of cases receiving high doses of whole-body external radiation,transferred from site hospitals.

1.6 OBJECTIVES AND SCOPE

The present guide has been prepared in order to provide guidance to medical and para-medical personnel regarding medical management of the different types of radiation accidents. Chapter 2 discusses briefly the physical aspects and biological effects of radiation, for the benefit of those who have not specialised in radiation medicine. The later sections of the chapter deal in detail with diagnosis, medical management and follow-up of persons involved in different types of radiation accidents. The implementation of the procedures described in this chapter calls for organisation of appropriate facilities and provision of requisite equipment as well as education and training of the staff. These aspects are addressed in chapters 3 and 4 of the guide. It is emphasised that major radiation accidents are rare events and the multi-disciplinary nature of the response required to deal with them calls for proper planning and continuous liaison among plant management, radiation protection personnel, first-aid assistants and medical & paramedical staff. The organisation and conduct of emergency drills may help in maintaining preparedness of the medical facilities for efficient management of radiation casualties.

Fig. 1.2 shows a flow chart of actions to be taken in different types of radiation accidents. Fig. 1.3 shows a form indicating particulars to be furnished by the plant to the personnel decontamination centre or the site hospital. Fig1.4 shows an identity tag which is to be attached to the radiation casualty at the first-aid post before transferring the casualty to the site hospital.

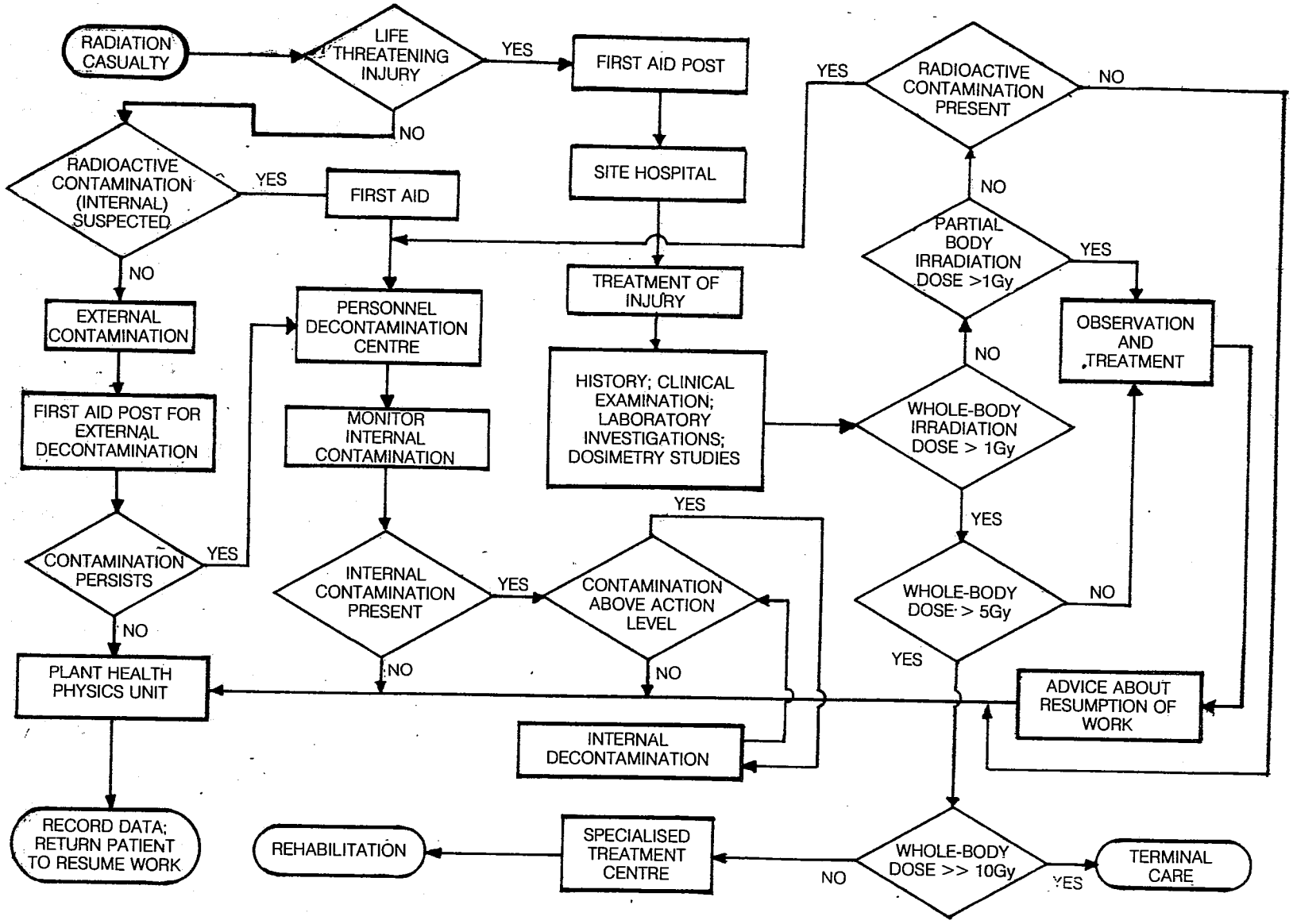


Fig. 1.2 FLOW-CHART OF SUGGESTED ACTION PLAN FOR MEDICAL MANAGEMENT OF RADIATION CASUALTY

ACCIDENT INFORMATION FORM

(To be filled by health physicist/person reporting)

1. Identification of informer :

2. Number and condition of uncontaminated patients:

3. Number and condition of contaminated patients:

4. Location of accident:

5. Nature of accident:
   (a) Irradiation condition:-
   Source -

   Distance-

   Time -

   Dose estimated -

   (b) Contamination (external) :-
   Radioactive nuclides involved -

   Activity level -

   Body area involved -

   (c) Contamination (internal):-
   Ingestion-

   Inhalation-

   (d) Contaminated wound -

   (e) Whether initial decontamination done -

6. Expected time of arrival of patients at the directed place-
   (Hospital to direct the informer where to deliver the patient)

Date: (Signature)

FIG.1.3 : SPECIMEN FOR ACCIDENT INFORMATION FORM

IDENTITY TAG

(FIRST-AID POST)

NAME :

DEPT : DIVN.

CONTAMINATION : Y/N

SITE OF CONTAMINATION :

INJURY : Y/N

SITE OF INJURY :

OVEREXPOSURE : Y/N

NAUSEA : Y/N , VOMITING : Y/N

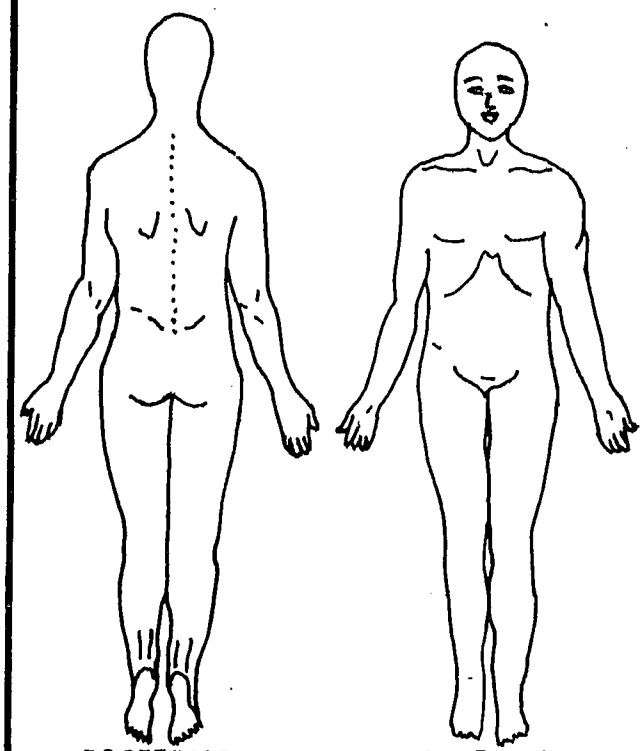
PRELIMINARY ACTIONS TAKEN :

TREATMENT :

FIRST AID :

DECONTAMINATION :

TO : PERSONNEL DECONTAMINATION CENTRE / SITE HOSPITAL



POSTERIOR ANTERIOR

(MARK THE LOCATIONS OF THE CONTAMINATION / INJURY)

Fig. 1.4 FRONT AND BACK VIEW OF THE IDENTITY TAG

Note: Contamination level should be expressed in dpm/100 cm^2 or over the affected area if less than 100 cm^2. Both alpha and beta contamination levels should be presented. If beta-gamma contamination levels are high, the level may be given in $\mu Gy\ h^{-1}$ (mrad/hr) measured with a side window G.M. probe with open window. An estimate of the total contamination should be given wherever possible. Both the initial level of contamination and the level of contamination while referring to Personnel Decontamination Centre/Site Hospital, should be given.

CHAPTER 2

DIAGNOSIS AND MANAGEMENT

SECTION 1

Radiation Physics

This section is intended to provide a basic understanding of the physical aspects of ionising radiations to those who have not specialised in radiation medicine.

2.1.1 IONISING RADIATION

Soon after the discovery of X-rays by W.C. Roentgen in 1895 and the discovery of the phenomenon of radioactivity (i.e. spontaneous emission of radiation by certain substances) by A.H. Becquerel in 1896, it was realised that biological damage is produced by absorption of energy from these radiations in living organisms. This energy absorption results in production of positively and negatively charged particles (called ions) in cells, causing disruption in the physico-chemical status of the cells. Other forms of radiation, e.g. visible light, heat etc., also affect the cell by exciting its constituent atoms. The term 'ionising radiation' is used when the transfer of energy from radiation to matter causes the ejection of electrons from the constituent atoms. Ionising radiations may be electromagnetic or particulate in nature.

X-rays and gamma-rays are electromagnetic radiations and are highly penetrating. The penetration depends on the wavelength. Gamma-rays in general have shorter wavelength than X-rays and are therefore more penetrating. The attenuation of X- and gamma-rays is exponential in nature. About 20 cm of concrete will significantly attenuate the intensity of X- or gamma-rays.

Beta-rays consist of very light particles, namely, electrons (about 1/2000th of mass of hydrogen atom) and carry a negative charge. Because of their electric charge, they do not penetrate tissue to the same extent as X- or gamma-rays. Even very high energy beta particles are stopped by a few millimetres of tissue. They dissipate their energy in a much smaller thickness of tissue and therefore cause greater superficial damage on skin. A thin sheet of aluminium or 1cm of plastic will completely stop even the most energetic beta particles emitted by radioisotopes.

Alpha-rays are heavy particles (about 4 times the mass of hydrogen atom) and carry a positive charge. Alpha particles are emitted by heavy radionuclides such as ^{210}Po, ^{226}Ra, ^{232}Th, ^{235}U and ^{239}Pu. Due to their heavy mass and strong electric charge, alpha particles are easily stopped even by a thin sheet of paper. They do not penetrate the outer horny layer of skin and do not therefore pose any external radiation problem. However, if alpha emitting radioisotopes are incorporated in tissues, they can cause great damage because of their ability to cause intense ionisation.

Neutrons are uncharged particles having approximately the same mass as hydrogen atom. They are more penetrating than alpha- or beta-rays. They do not cause ionisation directly, but do so indirectly through the charged particles which they release upon interaction with the atomic nuclei. All the types of radiation (alpha, beta and gamma) are produced by interaction of neutrons with atomic nuclei.

2.1.2 RADIATION DOSIMETRY

As mentioned earlier, radiation causes excitation and ionisation of atoms in matter. These processes lead to transfer of energy from radiation to the matter with which it interacts. The unit of radiation dose is therefore defined in terms of energy absorption per unit mass of matter with which radiation interacts. The SI unit of absorbed dose is called gray (Gy) which corresponds to 100 rad, the earlier unit.[3]

Exposure to X- and gamma-rays is measured in terms of a quantity called air kerma. The earlier unit, used for measurement of exposure, was based on ionisation produced in air and was called the roentgen (R), which approximately corresponds to 1 cGy (1 rad) in tissue.

Different radiations vary in their effectiveness to cause biological damage. To describe the equivalence of different types of radiation with reference to a biological end point (e.g. cell killing or transformation, chromosomal damage) radiobiologists make use of a quantity called Relative Biological Effectiveness (RBE). Experimentally determined RBE values for a wide variety of cells, for various energies of different types of radiation and for different biological end points, are reported in the literature. For purposes of radiation protection (mainly limitation of carcinogenic and mutagenic effects), the International Commission on Radiological Protection (ICRP) has recommended the use of a quantity called "Quality Factor" (Q), to achieve the same degree of protection for different types of radiation[4]. ICRP has recommended the use of the following values of Q for protection purposes[6](Table 2.1.1) :

TABLE 2.1.1 : QUALITY FACTORS OF DIFFERENT RADIATIONS

Radiation Type	Q
X-rays, gamma-rays, beta-rays	1
Neutrons	10*
Alpha-rays	20

* In a statement issued after Paris (1985) meeting, ICRP has recommended the use of a value of 20 for Q for fast neutrons[6].

The dose-equivalent (H) is a quantity obtained as the product of dose and quality factor, i.e. H=D.Q. The SI unit of dose equivalent is called sievert(Sv), which is equal to 100 rem, the earlier unit[4].

ICRP has considered the risks when tissues or organs are selectively irradiated by ingested or inhaled radionuclides and has introduced a quantity called "Weighting Factor" (W_T)[4] which is based on radiation-induction of fatal cancers in the exposed individual and serious hereditary disorders in the first two generations of offspring of the exposed individual. The values of W_T recommended by ICRP, for different tissues and organs are given in Table 2.1.2

TABLE 2.1.2 : TISSUE WEIGHTING FACTORS[5]

Tissue/Organ (T)	W_T
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Bone surface	0.03
Thyroid	0.03
Remainder(5 tissues/organs)	0.30

The sum of the products of dose-equivalent H_T in tissue (T) and its weighting factor (W_T) is called Effective Dose Equivalent $H_E=\Sigma W_T H_T$. The earlier unit of effective dose-equivalent is rem; its SI unit is sievert (Sv)[4]

It should be noted that in the case of acute radiation injuries (with which we are concerned in this guide), it is customary to use the quantity dose (in rad or Gy) and specify separately the other parameters, e.g. type and energy of radiation, dose-rate, dose distribution. The use of factors such as Q, W_T (recommended by ICRP for purposes of radiation protection) is inappropriate for evaluation of acute radiation injuries.

The quantity called "activity" is used to define the strength of a radioactive source. Activity is the rate of transformation of the radioactive source from one atomic species into another. The earlier unit of activity is called curie. 1 curie (Ci) (originally the activity of 1 g of radium -226) corresponds to 3.7×10^{10} transformations/sec. The SI unit of activity is called becquerel (Bq). 1 Bq = 1 transformation/sec. 1 Ci = 3.7×10^{10} Bq; 1 Bq=2.7×10^{-11} Ci.

The multiples and fractions of the above radiation protection units, which are commonly used, are as shown in Table 2.1.3.

TABLE 2.1.3: FRACTIONS AND MULTIPLES FOR SI UNITS

Fraction		Multiple	
Femto (f)	$= 10^{-15}$	Kilo (k)	$= 10^{3}$
Pico (p)	$= 10^{-12}$	Mega (M)	$= 10^{6}$
Nano (n)	$= 10^{-9}$	Giga (G)	$= 10^{9}$
Micro (μ)	$= 10^{-6}$	Tera (T)	$= 10^{12}$
Milli (m)	$= 10^{-3}$	Peta (P)	$= 10^{15}$
Centi (c)	$= 10^{-2}$	Exa (E)	$= 10^{18}$

Since 1/100th of Gy or Sv equals 1 rad or rem respectively, the fraction "centi" is also used in radiation protection and radiobiology literature.

SECTION 2

Biological Effects of Radiation

As mentioned earlier, radiation causes ionisation in matter with which it interacts. This ionisation produces lesions in the biological macromolecules; this is known as the direct action of radiation. Biological materials contain a large proportion of water and radiation produces certain extremely reactive chemical species, called free radicals, upon interaction with water molecules; these free radicals in turn react with the biological macromolecules; this is known as the indirect action of radiation[7].

Among the biological macromolecules, effects produced on deoxyribonucleic acid (DNA) are considered to be the most critical. The lesions produced in DNA molecule may be repaired either error free or error prone. The erroneous repair of the lesions leads in turn to changes in genes (transformation or mutation) and in chromosomes (aberrations and anomalies) and ultimately results in functional impairment or non-viability of cells.

Several factors -- physical, chemical and biological -- modify the effects of radiation, expressed at the cellular level. These include type and energy of radiation, dose, dose-rate, dose fractionation, temperature, presence of sensitising or protective chemicals, degree of oxygenation of cell and in the case of proliferating cells, the phase of cell cycle and cell maturation or differentiation.

A substantial loss of cells through cell killing caused by radiation leads to loss of tissue function. The tissues vary greatly in the rates at which the constitutent cell types are replaced; the production/division, differentiation, aging and loss of cells in a tissue are determined by tissue kinetics. Tissues, therefore, vary widely in their sensitivity to radiation. Tissues composed essentially of rapidly proliferating cells, such as epidermis, epithelium of intestinal mucosa, germinal epithelium and bone marrow are very sensitive.

The effects of radiation, expressed mainly through cell killing and loss of tissue function, are classified as non-stochastic effects[8,9]. These effects have a dose threshold, below which they are not observed and the severity increases with dose.These effects are discussed further in this chapter in relation to diagnosis and management of accidental radiation injury.

Cell transformation or mutation leads to another class of effects, called stochastic effects, which are expressed in the exposed individual after a considerable lapse of time or in his descendants[10]. The stochastic effects are believed to have no dose threshold and the probability of induction of the effect (rather than the severity) is a function of the dose. The most important stochastic effects of radiation are induction of cancer and hereditary effects.

Direct evidence of radiation induction of cancer in human beings has come from a number of radioepidemiological studies, notably on the survivors of atomic bombing of Hiroshima and Nagasaki, persons exposed to radiation from nuclear weapons testing (military observers as well as populations in the vicinity of test sites), occupational groups such as pioneer radiologists, uranium miners, radium dial painters, and workers in nuclear industry, and patients exposed to radiation for diagnosis, mainly detection of breast cancer and for treatment of cancer and certain benign diseases. The data from these studies have been reviewed by national and international bodies such as the Committee on Biological Effects of Ionising Radiations (BEIR) of US National Academy of Sciences[11], United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)[12] and the International Commission on Radiological Protection (ICRP) and lifetime risk coefficients have been derived for radiation induction of different types of cancer, averaged for the two sexes and over different age and population groups. The risk coefficients, assumed by the ICRP in Publication 45 (1984)[13] for purposes of radiation protection, are shown in Table 2.2.1

TABLE 2.2.1: FATAL CANCER RISK COEFFICIENTS

Organ/tissue	Risk of Fatal Cancer induction ($10^{-2}Sv^{-1}$)
Breast	0.25
Bone marrow	0.20
Lung	0.20
Thyroid	0.05
Bone	0.05
Skin	0.01
Other organs/tissues	0.50
Total	1.26

There is no conclusive evidence of radiation induction of genetic damage in human beings, even though it has been demonstrated in insects and laboratory animals. UNSCEAR (1988)[12] has derived risk coefficients for different types of genetic damages on the basis of induction of specific locus mutations and dominant mutations for cataract and skeletal defects. These are shown in Table 2.2.2.

TABLE 2.2.2 :INCIDENCE OF GENETIC DISEASE AT EQUILIBRIUM FROM PARENTAL EXPOSURE[12]

Disease Classification	Incidence,$10^{-2}Gy^{-1}$(Low LET)
Chromosomal anomalies	0.04
Dominant and X-linked	1.0
Recessive	0.15
Multifactorial	-
Total	1.19

ICRP has used a risk coefficient of 0.40 x 10^{-2} Sv^{-1} for radiation - induced hereditary effects in the first two generations of the offspring of the exposed individual[5,13]. It is concluded that among the stochastic effects, radiation-induction of cancer is of greater concern.

The system of dose limitation for radiation protection, recommended by the ICRP[5], aims at prevention of the non-stochastic effects and limitation of the stochastic effects induced by radiation. It consists of the following three components.

(a) *Justification of practice :* No practice (entailing exposure of individuals to radiation) shall be adopted unless its introduction produces a positive net benefit.

(b) *Optimisation of protection:* All exposures (to radiation) shall be kept as low as reasonably achievable(ALARA), economic and social factors being taken into account.

(c) *Dose limits:* The dose-equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.

For occupationally exposed persons, the annual dose-equivalent limit H_E for uniform whole-body exposure is 50 mSv (5 rem). Where individual tissues or organs are selectively irradiated, the annual dose equivalent H_T in any tissue or organ (other than eye lens) shall not exceed 500 mSv (50 rem), and in the eye lens it shall not exceed 150 mSv (15 rem) provided that the annual effective dose equivalent ($H_E=\Sigma W_T H_T$) does not exceed 50 mSv (5 rem). Doses from both external radiation and internal radioactive contamination are included in these dose limits. Exposure from natural radiation and medical exposures (meaning intentional exposure of patients for diagnostic or therapeutic purposes) and exposures resulting from the artificial replacement of body organs or function (e.g. by heart pumps and cardiac pacemakers) are not included in the above dose limits. In the case of women of reproductive capacity the Commission believes that occupational exposure at an approximately regular rate will provide appropriate protection, including during the period when pregnancy may not be diagnosed; the Commission recommends that when pregnancy has been diagnosed; arrangements should be made to ensure that the woman can continue to work in such conditions that it is most unlikely that the annual exposure will exceed three-tenths of the dose-equivalent limit for uniform whole-body exposure (i.e. 15 mSv or 1.5 rem). For further explanations regarding the ICRP system of dose limitation, reference should be made to ICRP publication 26[5]. The annual limits of intake through ingestion and inhalation are given in ICRP publication 30 for several radionuclides[14].

SECTION 3

Localised and Partial Body Irradiation

2.3.1 GENERAL

Much of the information on effects from localised exposure to radiation has been derived from radiotherapy. In radiotherapy of cancer, normal tissues are unavoidably included in the treatment volume. The damaging effects in these normal tissues set the limits to the dose which can be tolerated. The tolerance dose is usually defined as the dose that will produce a small but detectable increase in complications resulting from radiation effects on normal tissues. Transient early damage or detectable but non-life-threatening damage are not considered to be dose-limiting in radiotherapy. It should be noted that the tolerance dose is not to be taken as a threshold dose which is concerned with long-term effects which alter significantly the quality or duration of a patient's life. The estimates of approximate threshold doses for clinically detrimental non-stochastic effects in various tissues, based on responses of patients to conventionally fractionated therapeutic X or gamma irradiation are age and organ dependent. The main non-stochastic effects due to acute exposures are shown in Table 2.3.1.

TABLE 2.3.1 MAIN NON-STOCHASTIC EFFECTS AND RELATED DOSES
(acute exposures)[15]

Organ	Effect	D_0(Gy)	D_{50}(Gy)
Whole-body	Vomiting	0.5	2
Bone marrow	Aplasia	1	3.5
Lung	Pneumonitis	6	9
Thyroid	Hypothyroidism*	10	300
Skin	Erythema	3	6
Eye	Cataract	1	3
Gonads	Transient Sterility	0.15	0.85
Embryo(2 wks)	Death	0.5	1.2

*After intake of I-131

2.3.2 SKIN [16,17]

Skin is vulnerable to external radiation exposure, particularly radiation from hard beta-ray emitting contaminants deposited on the epidermis. Damage to varying extent can be seen, following radiation therapy and accidents involving high level exposure to X- and gamma-ray sources. Skin reaction is related to absorbed dose, which in turn is dependent on the type (particulate or electromagnetic) and energy of radiation. Beta particles deposit their energy within a short range and hence are more damaging. Among electromagnetic radiations, low-energy X-rays are more damaging than high-energy gamma-rays for the same reason.

There may be a history of exposure due to handling of a radioactive source or working with X-ray machines, or accelerator beams. Sometimes, there may be no history of exposure and the patient may complain of burn-like symptoms without any apparent cause. Radiation effects on skin develop slowly and blister formation occurs usually in about 2-4 weeks. The shorter the latent period, the more severe is the radiation burn.

The earliest damage seen is the transient erythema which develops immediately after exposure and is due to dilation of capillaries caused by histamine-like substances released by injured epithelial cells. This is followed 2-4 weeks later by fixed erythema which may come in waves and is much deeper and more prolonged than the transient erythema. Erythema may not be easily recognised in pigmented or exposed areas of skin. If the dose is more than 30 Gy (3000 rad), epilation, dry and moist desquamation and ultimately necrosis of the epidermis result. Long-term sequelae are pigmentation, atrophy of dermis, sweat glands, sebaceous glands and hair follicles, fibrosis of dermis and

increased susceptibility to trauma and chronic ulceration. Damage to germinal cells in the basal layer is critical in the pathogenesis of erythema and desquamation. It is the dose to these cells that determines the severity of skin damage.

Transient erythema : This appears within 2-3 hours of the accident, following moderate exposure at high dose-rates. The patient may complain of a sensation of warmth in the affected area. At very high dose (50 Gy or 5000 rad), the symptoms may be severe pain and a feeling that the affected part is on fire. This transient erythema lasts for a short time -- hours to days.

Fixed erythema: The transient erythema is followed 1-4 weeks later by fixed erythema, which is similar to that of a first degree thermal burn. At moderate doses (of the order of several Gy or hundreds of rad) the effect does not progress beyond the erythema stage. Photograph 1 in Plate-I shows the erythema on the palm of a worker, exposed to a dose exceeding 6 Gy (600 rad) of ^{60}Co gamma-rays.

Desquamation: These reactions, produced by radiation at doses exceeding 12 Gy (1200 rad), are primarily due to killing of cells in the basal layer and the associated appendages. The severity of the reactions depends on several factors such as anatomical location, vascularity and oxygenation of skin, genetic background, age and hormonal status of the exposed individual. The degree of desquamation depends markedly on the area of skin irradiated. Moist desquamation is produced within 2-3 weeks in 50% of individuals after a dose of about 20 Gy (2000 rad) to an area 35-50 cm^2 of skin. Photograph 2 in Plate-I shows a case of moist desquamation i.e. ulceration of thumb.

Transepidermal burn: This is similar to second degree thermal burns with a latent period of 1-2 weeks. Radiation burns are sometimes deceptive on superficial appearance since damage to important organs in subcutaneous tissue, viz. nerve endings, hair follicles, sweat glands, endothelium of blood vessels, may not be obvious. Among these, injury to the endothelium of blood vessels is the most serious. It produces endartritis obliterans, leading to necrosis of overlying tissues, which continues to progress for several months. The severity of the burn depends on the dose and at doses of 20 Gy (2000 rad) or above, blistering and skin loss may take place. In such cases, besides subcutaneous tissue, other structures are affected and may give rise to radiation necrosis of bone, muscle and other internal organs. Initial symptoms are erythema, pain, swelling, itching or tingling.

Photograph 3 in Plate -I shows the development of radionecrosis in the thigh of a person exposed to a dose of about 25 Gy from an ^{192}Ir industrial radiography source.

Full thickness radiation burn: This is similar to third degree thermal burns and a more serious version of transepidermal injury. This injury extends into the dermis and produces prompt and severe pain. In case of damage to circulation, the healing will take a long time and surgical intervention may be required.

Pain is an important feature of the exposure of skin, particularly in the extremities, to high doses of radiation. This pain is maximum with the appearance of vascular lesions. The pain is experienced during the first few days, lasting several hours and it may last for long periods.

Epilation: Loss of hair occurs after exposure to doses in excess of 3-5 Gy (300-500 rad), which is seen 2-3 weeks after the exposure. With doses upto 7 Gy (700 rad), the hair will regrow eventually. But at higher doses the hair follicles are destroyed and the hair does not grow again. Hair on the scalp is more sensitive than face or body hair.
Table 2.3.2 summarises the threshold doses of X- or gamma-rays for the different effects on skin.

TABLE 2.3.2 :THRESHOLD DOSES FOR SKIN EFFECTS.

Effect	Threshold dose Gy(rad) of X- or gamma-rays
Erythema	3 Gy (300 rad) (100 keV x-rays) 6-10Gy (600-1000 rad) (1000 keV x-rays)
Desquamation	15Gy (1500 rad)
Ulceration	20Gy (2000 rad)
Radionecrosis	25Gy (2500 rad)
Gangrene	30Gy (3000 rad)

Dose to skin due to the beta components of radionuclides must be estimated very carefully. Low-energy beta contamination of skin may present special problems when estimating the dose to basal cell layers, which is the relevant

tissue. The reason is that much attenuation takes place in the outer layers even when the beta energy is upto 200-300 keV. The same holds true for low energy photons of 10-15 keV whose effect on the skin is akin to that of beta rays. However, photons of more than 50 keV energy can affect deeper layers of skin.

MANAGEMENT OF RADIATION BURNS

History

The patient may come with any of the stages or symptoms described above. The following information should be obtained for management of the case :

1. Name of the patient :

   Sex: Age:

2. Details of the accident:

   Date Time

   Nature of accident

   Type of radiation and energy

   Possibility of whole-body exposure (anorexia, nausea, vomiting, diarrhoea)

   Possibility of radioactive contamination:

3. History of transient erythema:

4. Presence of fixed erythema, epilation, oedema or evidence of burns.

In certain cases, the patient may not be aware of irradiation and the dose may not be known. In these instances the time at which transient erythema occurred, along with any other symptoms, will enable the physician to come to a rough conclusion regarding the dose and the ultimate prognosis, with the development of fixed erythema.

Investigations

The following investigations are recommended:

1. Complete Blood Count
2. Blood lymphocyte culture and chromosomal analysis
3. Sperm count
4. Culture and antibiotic sensitivity test (AST).
5. Estimation of radionuclides in urine and stools, (if needed)
6. Serial colour photography
7. Thermography
8. Non-invasive vascular studies
9. Radioisotope scintigraphy
10. Slit lamp examination of eye (for cataract)
11. Physical dosimetry

Samples should be taken immediately for items 1-5 in the above list. Concurrently photographs should be taken and the dosimeters sent for evaluation of dose. Scintigraphy may be done before slit examination in view of blood contamination with ^{99m}Tc.

Even after the area of the burn becomes apparent, the underlying damage cannot be observed with accuracy clinicaly. Thermography [Photograph 4(a) in Plate-I] and scintigraphy [Photograph 4(b) in Plate -I] offer a means of detecting areas affected significantly by localised irradiation, and the functional status of the organ. This information is helpful in planning any surgical intervention without waiting for the clinical symptoms to unfold fully. It will obviate much of the needless suffering to which the patient is subjected to.

If there is leukopenia in the first week, it is suggestive of whole-body exposure. There is danger of infection which should be treated vigorously. Surgical intervention should be kept to the minimum during this phase of bone marrow depression which usually lasts about 4-8 weeks.

Surgery

Decision for amputation and reconstructive surgery depends on the following determinants:

a. Intractable pain
b. Size and location of injury
c. Degree of control over infection
d. Degree to which vascular damage can be estimated
e. Value of the part.

Photograph 5 in Plate -II shows gangrene of thumb and index finger of both the hands of a worker exposed to gamma-rays from an ^{192}Ir industrial radiography source. Photograph 6 in Plate -II shows the case after amputation of the affected fingers.

Specific Treatment :

Mild Erythema

The skin may become dry and start itching after 3-4 weeks. A bland lotion or steroid ointment should be applied locally. Clothing should not be worn tight over the affected part.

Transepidermal Burn

Pain should be relieved by analgesics, and drugs like phenylbutazone, which cause bone marrow depression should not be used. Sterile protective dressings should be used. Systemic antibiotics should be given for prevention of infection. Usually the burn will heal without skin grafting in the absence of infection.

Full Thickness Radiation Burn

Here, the burns may progress from initial blistering to skin loss and deep tissue necrosis, giving rise to severe pain, tissue loss and infections. This will require surgical intervention, the timing of which will be difficult to decide due to slow progression of burn. Bone marrow depression may further complicate the condition. In case there is leukopenia at 2-6 weeks, surgical treatment should be kept at minimum until haematopoietic recovery takes place (usually in about 6-8 weeks). In case the involved area is more than a few sq. cm (2-3 cm^2), skin grafting will be required. Larger areas involving necrosis and gangrene (Photograph 7 in Plate-II) of distal portions of fingers or extremities will require excision and amputation. In beta-ray burns, early excision and skin grafting may spare the patient much pain. Follow up of such cases is important because healed radiation burns may result in weak atrophic skin that is subject to chronic and recurrent ulceration.

Chronic Radiodermatitis

Dry atrophic, hairless skin with numerous telangiectatic areas is more prone to squamous cell or basal cell carcinoma which develops after 10-20 years. The doses required to produce late skin sequelae are likely to be in excess of 10 Gy (1000 rads). If the dose is protracted over a period of more than 30 days, chronic sequelae can occur without acute skin reaction or development of chronic dermatitis.

2.3.3 EYES[18]

The eye lens is generally considered to be the most radiosensitive structure in the eye. Radiation causes damage to the dividing cells in the anterior epithelium located in the equatorial region of the lens. The lens does not have blood supply and therefore has no mechanism for cell removal. The damaged cells are translucent and if an adequate number of damaged cells are accumulated, they become an opthalmologically detectable opacity. At low doses (less than 3-5 Gy, or 300-500 rad, of low-LET radiation), the opacities may take several years to develop, remain microscopic and do not cause any significant impairment of vision. At high doses of low-LET radiation, the opacities (cataract) develop within months, progress rapidly and cloud the lens completely. Fast neutrons have a lower threshold for induction of cataract as compared to low-LET radiation; available experimental data seem to imply an RBE of 2-3 for neutrons for cataract induction as compared to low-LET radiation. For protracted exposures, much higher doses (>8Gy) are required before the effects are noted. A latent period of several months to several years is present before the initial opacities are observed in the lens. Radiation cataracts do not necessarily progress to cause complete loss of vision.

2.3.4 GONADS

The ovary contains a limited number of germ cells, approximately about 400,000 follicles in a young girl (12-16y) and declines to about 8,300 follicles in a woman (40-44y), which are not replaced if they are depleted[19]. The killing of these germ cells by radiation can, therefore, impair fertility. The mature oocyte is the most radiosensitive among the various maturation stages of the germ cell[20]. An acute exposure of both ovaries to a dose in excess of 0.65-1.5 Gy (65-150 rad) may cause reduced fertility or temporary sterility. At doses below 2-3 Gy (200-300 rad) large enough number of immature oocytes may survive to restore fertility eventually. A single dose above these levels may cause permanent sterility. The threshold for permanent sterility decreases with age, presumably due to loss of oocytes through aging and ovulation, without any replenishment.

In the testes, spermatogonia, in early stage of stem cell differentiation, are more radiosensitive than germ cells of earlier or later maturation stages, including spermatocytes, spermatids and spermatozoa, the last being most resistant[20]. In man, an acute exposure of both testes to a dose as low as 0.15 Gy (15 rad) can cause a significant depression of the sperm count. This depression may take place after several weeks when the more mature germ cell stages are eliminated from the spermatogonic cycle. Fertility is restored if enough stem "spermatogonia" survive to repopulate the seminiferous tubules. The recovery may take several years after a high dose. If the dose to the testes exceeds 3-5 Gy (300-500 rad) few stem cells will survive and permanent sterility may result since repopulation is slow and incomplete.

2.3.5 IN-UTERO IRRADIATION[21,22]

Development of human being in utero may be divided roughly into three periods: (a) Pre-implantation, extending from fertilisation to settling of the embryo in the uterine wall (0-8 days post-conception), (b) major organogenesis (9-60 days p.c), characterised by formation of the main body structure and (c) foetal period (60-270 days p.c.) during which growth of the structures already formed takes place. Death of the embryo is considered to be the most conspicuous effect of radiation in the pre-implantation period. The acute median lethal dose (LD_{50}) for the human embryo is considered to be about 1 Gy (100 rad). Induction of malformations is considered to be the most characteristic type of damage produced by radiation during the period of major organogenesis. Although radiation induced malformations in different body structures have been observed in experimental animals, those involving the central nervous system have been more common in human beings. A study of about 1600 children exposed in utero at Hiroshima and Nagasaki to various doses and at different stages of gestation showed that 30 children had severe mental retardation. Severe mental retardation was defined as inability of the individual to perform simple calculations, to make simple conversation, to take care of oneself and requiring institutional care. The observed incidence of severe mental retardation was far higher than what could be normally expected in such a group. Correlation with the stage of gestation suggests that the period 8-15th week p.c. may be the most vulnerable. The rate of increase with dose, of severe mental retardation in children irradiated during this period, is calculated to be 0.4 Gy^{-1}. The rate of increase for those irradiated during the period of 16-25th week p.c. was 0.1 Gy^{-1}. There is no evidence of radiation related mental retardation, either in the interval from fertilisation upto the 7th week or after the 25th week p.c. The effects of radiation during the foetal period are considered to be an increased incidence of childhood malignancies. The acute median lethal dose (LD_{50}) for radiation during the foetal period is considered to be about 3-4 Gy (300-400 rad). UNSCEAR[10] has attempted to quantify the risk for a number of radiation induced effects in utero, including mortality, induction of malformations, mental retardation, and malignancies. It is concluded that for small doses likely to be encountered in practice the overall risk is relatively small (no more than 2×10^{-2} per liveborn per cGy) in relation to the natural incidence of malformations in non-irradiated individuals (6×10^{-2} per liveborn).

SECTION 4

Whole Body Irradiation

2.4.1 ACUTE RADIATION SYNDROME

This is a relatively rare event caused by exposure of whole body to moderately high to very high doses of penetrating radiations. About 300 persons, all over the world, have received such exposure in radiation accidents, including about 237 persons in the Chernobyl power reactor accident in USSR. The clinical effects in such accidents depend upon:

1. Nature of radiation
2. Duration of exposure
3. Total dose
4. Dose rate
5. Dose distribution in the body (spatial and temporal)

Accidents in nuclear installations generally may involve all types of radiations including neutrons. In criticality accidents there is a sudden release of large amounts of radiation energy, which occurs when a sufficient mass of fissile material such as ^{235}U, ^{239}Pu are assembled in a configuration so as to cause an uncontrolled nuclear fission chain reaction. The radiation dose is delivered in a short time and produces severe biological damage. Complications may arise because of any concomitant injury, e.g. thermal burns and high levels of radioactive contamination or exposure to high concentrations of high energy beta-emitting radioactive noble gases resulting in severe damage to skin and mucosa, as was experienced in Chernobyl power reactor accident[23]. In contrast to this, if the dose is received over a longer period, such as in accidents involving radioisotope sources, the clinical effects are less for the same dose. In radiotherapy, protraction of dose is utilised to spare the patient from undue damage to surrounding normal tissues/ organs, even though high doses of radiation are given to specific tissues in which malignancy is present.

Acute radiation syndrome represents the clinical manifestation of damage to many important organs and systems. Those organs in which the cells are continuously replaced are more radiosensitive, e.g. skin, haematopoietic and gastrointestinal systems; at very high doses, symptoms pertaining to the central nervous system appear. The clinical manifestations of acute radiation syndrome unfolds in four stages[24].

1. Prodromal phase
2. Latent period
3. Manifest illness
4. Recovery phase

Prodromal Phase

The signs and symptoms during this phase are:

- Headache
- Anorexia
- Nausea
- Vomiting
- Diarrhoea
- Weakness
- Apathy
- Prostration
- Irritability
- Perspiration
- Erythema
- Conjunctivitis
- Fever
- Respiratory distress
- Tremors
- Hyper excitability
- Ataxia

The time period involved is usually 3-4 days.

Latent Period

There are few clinical symptoms during the latent period. This period lasts usually 2-3 weeks. At high doses there may not be any latent period and the patient deteriorates rapidly towards the phase of manifest illness.

Manifest Illness

The following signs and symptoms are seen during this phase:

- Anorexia
- Nausea
- Vomiting
- Diarrhoea
- Fever
- Weight loss
- Infection
- Haemorrhage
- Erythema
- Epilation
- Aspermia
- Shock
- Disorientation
- Convulsions
- Coma

Clinical Syndromes

Four types of clinical syndromes are associated with acute irradiation[25]:-

1. Neurovegetative syndrome
2. Haematological syndrome
3. Gastrointestinal syndrome
4. Neurological syndrome

2.4.2 NEUROVEGETATIVE SYNDROME

It appears at doses of 1 Gy (100 rad). The main symptoms are:

1. Vomiting in 5% of cases
2. Minimal changes in blood picture
3. Chromosomal changes above 0.1 Gy (10 rad)

2.4.3 HAEMATOLOGICAL SYNDROME

In the dose range 1-10 Gy (100-1000 rad) it is the haematopoietic system which suffers a major damage. Vomiting is seen after 3 hours in 50% of cases with a dose of 2 Gy (200 rad) and in 1 hour in 100% of cases with a dose in excess of 5 Gy (500 rad.). At the peak of the manifest illness, the subject may haemorrhage from skin, mucous surfaces or internal organs, and will also be susceptible to infection. Blood examination will reveal leukopenia, lymphopenia,thrombocytopenia and anaemia after initial increase of polymorphs. Skin will show transient erythema after 2-3 hours, fixed erythema after 2-3 weeks and transient epilation after 3 weeks.

Critical period : **2-6 weeks**

Death occurs due to haemorrhage and infection within 2 months. The median lethal dose for acute whole-body irradiation is considered to be around 4-6 Gy (400-600 rad) for adult human beings, if no medical treatment is given. However, with conventional treatment, $LD_{50/60}$ will be around 5 Gy (500 rad).

2.4.4 GASTROINTESTINAL SYNDROME

The general sequence of events after whole-body exposure to doses around 8-10 Gy (800-1000 rad) is as follows: Initially the symptoms during the prodromal phase are nausea, vomiting and at higher doses, diarrhoea. The onset of these symptoms will depend on the dose received. The appearance of symptoms within two hours of exposure is indicative of high doses. At doses in the range 10-20 Gy (1000-2000 rad) symptoms appear in less than an hour. Besides anorexia, nausea and vomiting, diarrhoea is seen, followed by shock with electrolyte imbalance and haemorrhages from skin and GI tract. Skin shows erythema, sub-epidermal injury and permanent epilation. The characteristic findings in blood are rapid fall of lymphocytes with absolute counts coming down to less than 100 cells/ mm^3 within 48 to 72 hours.

The prodromal phase may be followed by a latent period during which there may be no symptoms. The latent period may last a few weeks. With doses in excess of LD_{50} i.e. in excess of 4-6 Gy (400-600 rad) the latent period may be reduced to 6-8 days. At high doses the clinical phases may merge altogether.

The third phase of the syndrome starts with vomiting, diarrhoea, severe fluid and electrolyte loss, followed by intestinal ulcerations and haemorrhage. The severe gastrointestinal upset merges with the haematological syndrome and is associated with haemorrhage from serous surface and bacterial infections due to severe bone marrow depression.

Critical period : 1-2 weeks

Death occurs due to circulatory collapse within 2 weeks.

Note: Following the experience in medical management of the radiation casualties in Chernobyl accident, mention is made of oro-pharyngeal syndrome, characterised by radiation mucositis in buccal cavity, vestibule of the larynx and the nasopharynx. This results in accumulation of enormous quantities of rubbery mucous in these sites.

NEUROLOGICAL SYNDROME

At doses of 50 Gy (5000 rad) and above, vomiting occurs immediately after exposure, followed by tremors, ataxia, convulsions and coma. Blood shows disappearance of lymphocytes altogether.

Critical period : 0-2 days

Death occurs due to cerebral oedema and respiratory failure within 2-3 days.

Note: A classification of the radiation casualties in the Chernobyl accident was made into four groups on the basis of degree of severity of prodromal symptoms.

Fourth degree (Extremely Severe)

Pronounced early (in the first half-an-hour) primary reaction (vomiting, headache, rise in body temperature) short latent period (6-8 days). Doses were in excess of 6 Gy (600 rad), estimated to be upto 12-16 Gy (1200-1600 rad) whole-body dose.

Third degree (Severe)

Development within 30 minutes to 1 hour of primary reaction (vomiting, headache, sub-febrile body temperature, transient erythema). Duration of latent period: 8-17 days. Doses were estimated to be in the range 4-6 Gy (400-600 rad).

Second degree : (High)

Development of primary reaction in 1-2 hours. Duration of latent period : 15-25 days. Doses were estimated to be in the range 2-4 Gy (200-400 rad).

First degree : (Moderate)

Primary reaction after 2 hours post irradiation. Absence of general skin reaction. Latent period longer than 1 month. Doses were estimated to be in the range 1-2 Gy (100-200 rad).

2.2.5 INITIAL MEDICAL MANAGEMENT

General Principles

Exposures associated with severe injuries and radioactive contamination : Life-saving measures will have precedence over decontamination.

Radioactive contamination : Reasonable measures (e.g. discarding of contaminated clothing at the site of accident), for removal/reduction of external/internal contamination as much as possible, should be taken at the first-aid centre of the plant, before the patient is sent to the site hospital. The site hospital should have facilities to receive, treat and care contaminated patient in the casualty ward.

Accident History

This is very important. Even at the slightest suspicion of the symptoms (nausea, vomiting, etc.) being attributable to radiation exposure, the patient should be sent at once to the site hospital so that investigations and medical surveillance are started promptly. The particulars mentioned in the Radiation Incident Reporting Form (Fig. 1.3) should be completed and given to the site hospital.

Clinical Examination

Physical examination of the patient should be conducted as soon as possible after the patient is received at the site hospital. The examination should be comprehensive. Normal and abnormal findings should be recorded. The lapse of time between the accident and the examination should be noted and a watch should be kept on the clinical pattern which will unfold later on. The findings from physical dosimetry (if readily available) should be recorded.

The prodromal symptoms which are readily detected, are of great value for a preliminary assessment of the dose and thus helpful for prognosis. The earlier the appearance of the prodromal symptoms and the more severe and sustained they are, the higher is the dose to the individual and the more difficult is his chance of recovery (cf Table 2.4.1) Psychosomatic factors in the low dose range and fractionation (and protraction) of the dose in high range influence the appearance and severity of the prodromal symptoms.

Laboratory Investigations

The laboratory investigations provide further corroboration of the preliminary dose assessment made on the basis of clinical symptomatology. It is emphasised that the required specimens, viz. blood, urine, stool should be obtained as early as possible after the accident to obtain base-line data and for dosimetric measurements. Depending upon the results, the investigations should be repeated, as necessary.

Blood

The haematopoietic system is at the greatest risk from radiation and changes occur in peripheral blood within hours of the accident, and provide a reliable measure of the severity of radiation exposure. The most useful indicator is the lymphocyte count. A fall to less than 1000 cells mm^3 in 24 hours signifies a serious exposure with grave consequences. The rate of fall of the lymphocyte count provides a measure of the dose; the faster the fall the greater is the dose. Complete blood count (CBC) should be done three-to six-hourly during the first 48 hours. Apart from CBC, blood grouping and lymphocyte typing should also be done in case bone-marrow transplant is contemplated.

Cytogenetic Examination

Analysis of chromosome aberrations in blood lymphocytes may be used for estimating the equivalent whole body dose. Radiation causes breaks in chromosomes and the broken ends can rejoin in a number of ways resulting in the formation of dicentrics, acentric rings and fragments. These aberrations are scored in about 100-500 cells. From these scores, particularly of dicentrics, a fairly good estimate of the equivalent whole-body dose can be obtained.

The application of haematological and cytogenetic techniques for biological dosimetry and for prognosis is discussed in detail in Chapter 3.

Biochemistry

Routine investigations help in management of shock and fluid loss and include:

- Fasting and post prandial blood sugar (F.B.S. and P.P.S.)
- Estimation of electrolytes (Na^+, K^+, Cl^-)
- Blood: CBC, platelet count, blood group, Rh, HLA type
- Urine: routine, microscopic and estimation of radionuclides
- Stool: estimation of radionuclides
- Liver function test
- Renal function test

Bacteriology

Culture and antibiotic sensitivity tests from any septic foci, and also culture from body cavities should be taken, alongwith cultures from sputum, stools and urine.

Electroencephalogram (EEG)

Neurological changes are seen in EEG with changes in the vigilance wave, that is, appearance of slow waves (4-6 Hz) which occur in burst and may be distributed uniformly or nonuniformly over the cerebral spheres. These waves appear, if the dose to the head is in excess of 4-5 Gy (400-500 rad). The changes are persistent particularly in cases of high doses. For doses of the order of $LD_{50/60}$ these EEG patterns take several years to disappear. At lower doses the interpretation is very difficult.

The results of various investigations must be recorded carefully in the Site Hospital in an appropriate form such as given in Fig. 2.4.1.

FIG.2.4.1 SPECIMEN FOR MEDICAL INFORMATION FORM

MEDICAL INFORMATION FORM

1. IDENTIFICATION OF THE PATIENT:

Full Name :
(In Block Letters)

Age : Sex :

2. IDENTIFICATION OF THE INDIVIDUAL WHO FILLS THE FORM

Name :

Designation :

Affiliation :

Date and hour of FORM FILLING

Date: Hour:

3. DATE AND TIME OF ACCIDENT:

Date of exposure: Presumed hour:

4. EXPOSURE CONDITIONS

DURATION / / / / / /

If possible, time beginning: / / / / /
end : / / / / /

Position of the patient
Nature of work of the patient

4.1 DOSIMETRY INFORMATION

The patient had a dosimeter yes no
Dosimeter recovered yes no

If yes: Dosimeter No. / / / / / / / / /

4.2 RESPIRATORY PROTECTION : yes no

4.3 CONTAMINATION OF CLOTHES (If detected) : yes no

Continued on next page

5. FIRST SYMPTOMS

5.1 CLINICAL STATE OF THE PATIENT
(Indicate time of appearance, number or duration, as applicable)

Nausea / / / / / (time)

Vomiting

Wound

Trauma

Burn

5.2 MEDICAL FINDINGS (to be filled by the physician)

Name of physician:
(In Block Letters)

Name of Patient:
(In Block Letters)

Date of examination Hour: / / / / /

asthenia: yes no

headache: yes no

nausea : yes no / / / / /
(time of appearance)

vomiting: yes no number :

diarrhoea: yes no quantity :

temperature: / / / / / /

pulse:

blood pressure:

consciousness: normal abnormal: agitation
delirium
sleepiness
coma

equilibrium disturbance: yes no
co-ordination disturbance: yes no
skin and mucosa:
oedema: yes no
erythema: yes no
other:

Continued on next page

6. TREATMENT AND INVESTIGATIONS

6.1 MEASURES TAKEN

Undressing: yes no

Decontamination: yes no

DTPA administration: yes no

If yes, administration pathway: *aerosol
*bathing
*intravenous

Stable iodine administration: yes no

6.2 LABORATORY TESTS

BLOOD SAMPLES

*First sample (If possible, before the third hour)

Date / / / / / Hour / / / / /

* Blood cell count,platelets: yes no

* Cytogenetic (10 ml): yes no

* Sample for spectrometry: yes no

* Second sample(If possible,2 hours after the first one)

Hour / / / / /

* Blood cell count,platelets: yes no

* HLA typing: yes no

URINE SAMPLES: yes no
(If possible, for gamma spectrometry)

Is it the first urination
after the accident ? yes no

7. DESTINATION OF THE PATIENT (IF SENT FOR FURTHER TREATMENT)

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8. PHYSICIAN'S CONCLUSIONS:

Date: (Signature)

2.4.6 THERAPY

General Principles

If the dose is less than 5 Gy (500 rad) time is usually available, to await the results from biological and physical dosimetric investigations and to confirm the prognosis made on the basis of prodromal symptoms. Therapy can be planned accordingly. A latent period usually exists between the prodromal phase and the appearance of manifest illness and the need for therapy. This latent period is variable, depending upon the severity of exposure. Cases which are or are suspected to be in the low dose range (1 Gy or 100 rad) do not usually call for hospitalisation. Cases in the median lethal dose range, around 4-6 Gy (400-600 rad) should be put in isolation with sterile facility. Follow up in the form of therapy would be case-specific and special forms of therapy may be required in these cases such as packed red cell transfusions and platelet transfusion. Bone marrow transplantation is indicated in those cases where the exposure is uniform and the doses are around 10 Gy (1000 rad). Those patients who had received a dose in excess of 15 Gy (1500 rad) are likely to require terminal care only. In these cases gastrointestinal symptoms will predominate. Besides maintenance of fluid and electrolyte balance, the treatment should be directed towards reducing the symptoms and making the patient as comfortable as possible.

Symptoms Control

The initial symptoms of nausea and vomiting should be controlled with 4 mg of dexamethasone i.v. or 100 mg of hydrocortisone hemisuccinate i.v. six hourly along with chlorpromazine 25 mg or metaclopromide 10 mg. i.m. Apart from this, in early stages of illness adequate rest, sedation and maintenance of morale are needed.

For anorexia and dryness of mouth zinc supplements are suggested alongwith minerals and vitamins.

Diarrhoea is controlled with codeine phosphate, kaolin and imodium.

For radiation dryness of skin,daily application of soft white vaseline or petroleum jelly is recommended.

Isolation Facility

If infections are to be prevented or treated properly, some kind of isolation facility will be required. Single room with sterile precautions and with a laminar air flow is best. Another method is life island bed in completely enclosed plastic unit with separate ducts/ports for ultravoilet irradiated filtered air with separate venting ports and gloves for examination of the patient and manipulation of instruments. Where these facilities do not exist, the patient can be isolated in a single room with reverse barrier nursing and room air sterilised by ultravoilet lamps. To minimise the risk of infection all supplies entering the room should be sterilised. Visitors should be restricted and those going into the room should wear masks, clean gowns and plastic aprons.

Prevention and Treatment of Infections

Antibiotics should be administered at an early stage. These can be prophylactic and specific antibiotics. Fever should be treated promptly.

For bacterial infections a combination of newer pencillins, like piperacillin and mezlocillin, gives good results. Gentamycin can be combined with one of the cephalosporins. Trimethoprim can be used for the sterilisation of the gut.

Particular problems could arise due to viral and fungal infections. Viral infections e.g. due to herpes simplex virus should be treated with acyclovir. Fungal infection should be initially treated with nystatin or new agents like miconazole and ketoconazole. Cases not responding to this therapy should be given amphotericin B. Any other associated infection should be treated with specific drugs. Fever not responding to all this antibiotic therapy should be given gamma globulin in high doses.

Haematologic Support

The haematopoietic system is mainly involved in the median lethal dose range. Haematopoiesis should be supported until spontaneous bone marrow recovery occurs which can be expected between 4-6 weeks post irradiation. Support is usually required around 3 weeks post exposure, and should be given in the form of packed red cell and platelet transfusions.

Above 10 Gy (1000 rad) bone marrow transplant (BMT) should be considered. BMT may be needed in the first week to counteract bone marrow aplasia. Allogenic matched bone marrow transplant from a family donor, ideally a twin or a male sibling, is done. It is necessary to have the donor matched with the recipient at the major histocompatibility complex. The success of BMT is limited by various complications including graft rejection, infection (bacterial, fungal and viral), acute or chronic graft versus host disease (GVHD). The hazards of this procedure would have to be compared with the risks from bone marrow failure before taking a decision.

Use of Experimental Drug Granulocyte Macrophage Colony Stimulating Factor (GMCSF) in Goiania,Brazil[26]

In Goiania, eight patients were given granulocyte macrophage colony stimulating factor (GMCSF) following whole-body exposure to Caesium-137 radiation. Out of them 4 patients who had received radiation doses in the range 4-6 Gy (400-600 rad) died as a result of complications (haemorrhage and infection). The four surviving patients treated with GMCSF had lower estimated doses of 2.5-4.4 Gy (250-450 rad). Two patients, who received higher doses of 6.5-7.1 Gy and exhibited severe bone marrow depression, but who did not receive GMCSF, survived. The role of GMSCF in the revival of bone marrow, after irreversible myelodepression, was not established. However, San Salvador experience[1] is suggestive of a positive response.

Nutrition and Nursing Care[27]

Food is prepared in a separate sterile kitchen. No uncooked food is supplied to the patient. Bread is rebaked and butter and chocolate are autoclaved. Frozen food, adequately stored and cooked, is satisfactory. Sterile water is needed. Drinks in cans do not usually require further sterilisation.

The nursing care of the irradiated person should be of the highest order. Intravenous feeding and drug administration casts a heavy burden on the nursing staff. All supplies entering the patient's room should be sterilised by heat or irradiation. Linen, blankets and all personal belongings of the patient should be sterile.

2.4.7 **FOLLOW UP**

Plans should be made for rehabilitation of the patient, following successful treatment and discharge of the patient from the hospital. These should include plans for his future employment including engagement in radiation work. Medical follow up (frequently in the first year after discharge from the hospital and half-yearly or annually later on) should also be done to look for late sequelae and long-term effects, described in Section 2 of this Chapter. Proper medical records of the history of investigations done, with their results, treatments provided and results of follow up study should be maintained for medico-legal purposes as well as for use in biomedical research of such cases.

SUMMARY

Table 2.4.1 gives a schematic classification of dose-ranges of whole-body exposure, symptoms, therapy and probable outcome.,

TABLE 2.4.1 WHOLE-BODY IRRADIATION IN MAN

SCHEMATIC CLASSIFICATION OF DOSE RANGES, SYMPTOMS, POSSIBLE THERAPY, CLINICAL COURSE AND OUTCOME

Acute Whole body dose, Gy(rad)	Prodromal symptoms (Nausea, vomiting, etc.)		Clinical Characteristics			Possible therapy, clinical course and outcome					
	Percent incidence	Time of onset	Organ systems involved (syndrome)	Characteristic symptoms	Critical period post irradiation	Therapy	Time until recovery	Prognosis	Lethality	If injury is fatal: Death occurring.. within	If injury is fatal: Usual cause of death
<1 (<100)	10%	>3hrs	-	-	-	-	-	-	-	-	-
1-2 (100-200)	50%	3hrs	**Blood forming tissues**	Mild leukopenia & thrombopenia	-	-	weeks	**Excellent**	-	-	-
2-5 (200-500)	50-100%	2hrs	**Blood forming tissues (Haemato-poietic Syndrome)**	Thrombopenia Leukopenia Haemorrhage Infections Epilation (>3Gy)	2-6 weeks	Optimal care (Isolation, anti-biotics, fluids, etc.)	Several weeks	**Fair**	0.50%	Months	Infection Bleeding
5-10 (500-1000)	100%	1to1/2hr	"	"	"	Transfusions of platelets, leukocytes; BMT	Months	Guarded; depends on success in therapy	50-90%	weeks	Infection, Bleeding
10-15 (1000 -1500)	100%	<1/2hr	**Gastro-intestinal system (Gastro-instestinal syndrome)**	Diarrhoea, Fever, Electrolyte imbalance, Hypotensive shock	3-14 days	Palliative, maintaining adequate blood pressure	-	Very poor	90-100%	2 weeks	Entero-colitis, Shock, Circulatory collapse
50 (5000) and above	100%	Minutes	**CNS and cardiovascular (Neurological syndrome)**	Cramps, Tremors, Ataxia, Lethargy, Disorientation, Impaired vision, Hypotensive shock	1-48hrs	Symptomatic, maintaining adequate blood pressure	-	**Hopeless**	100%	1-48hrs	Cerebral oedema

SECTION 5

Radioactive Contamination: External

2.5.1 GENERAL CONSIDERATIONS

Minor skin contaminations occur from time to time in laboratories, facilities and installations where radioactive materials are handled in open form. The potential for and the magnitude of external contamination depend upon the amount of radioactive material handled, the nature of the operations conducted and the handling facilities provided, including the safety features in the design and the equipment and tools used for the operations. Generally, the workers are trained in the safe handling of radioactive materials and are required to wear appropriate protective clothing, such as apron, coverall, rubber gloves, plastic suits and respirators (where necessary) while engaging in radioactive operations and to monitor themselves for radioactive contamination using suitable instruments such as frisker, hand, clothing and shoe monitor before leaving the radioactive zone. Nevertheless, incidents resulting in external contamination, particularly clothing, hands, face, eyes, hair and scalp, may occur due to equipment failure and more frequently due to operator error.

Radiation Effects

External contamination is usually not attended with serious medical management problems. Some radioisotopes, notably tritium and iodine, are easily absorbed through the intact skin. Injury may be caused by the chemicals (acids, alkalis or organic solvents) which may facilitate absorption of the radioactive material through the skin or due to fire or explosion. Depending upon the severity, such injury must promptly receive first-aid and medical attention.

The effects of radioactive contamination on the skin depend upon the type and energy of the radiation emitted by the radioactive material. Alpha particles do not penetrate the horny outer layer of skin (epidermis). The main problem associated with alpha emitters is the possibility of transfer into the body by absorption through intact or broken skin, inhalation or ingestion (e.g. eating with contaminated hands). On the other hand, beta particles penetrate the epidermis and cause intense irradiation of the tissues and structures beneath the epidermis and are therefore a major hazard. Some Japanese fishermen were accidentally exposed to radioactive fallout from nuclear weapons testing in 1954. Due to intense beta radiation emitted by the fission products, the fishermen developed skin itching followed by radiation burns and epilation. Healing of the radiation burn took place after some time and the hair grew again after a few months. During the recent Chernobyl power reactor accident too, workers inside the reactor building developed radiation injury of the skin due to beta rays from short-lived fission products deposited on the skin. Electromagnetic radiation (X- and gamma rays) can also cause damage but because of their greater penetration they deposit less energy locally than beta rays. Low energy rays cause more biological damage superficially than gamma rays.

The objectives of skin decontamination are to remove as much of the radionuclide from the skin as possible to reduce the surface dose rate and to avert internal contamination.

The following maximum permissible levels have been specified by Health Physics Division, BARC for fixed contamination on the skin:

Alpha emitters : 0.4 Bq. cm^{-2}

Beta emitters : 4.0 Bq. cm^{-2}

In the majority of cases of external contamination, the radioactive material can be removed using the simple general procedure described below. Such decontamination is best done in a first-aid post within the laboratory, facility or installation. The location and design of the first-aid post as well as the facilities and supplies which should be available there are described in Chapter 3. Cases of skin contamination concomitant with traumatic injury or suspected intakes through inhalation and cases where the contaminant is not removed by the general procedures described below should be promptly referred to a decontamination centre where the patient can receive further attention from properly

trained medical staff. The decontamination centre is discussed in Chapter 3.

Precautions

The patient should be monitored carefully to determine the nature, extent and degree of contamination. The complete body should be monitored. If the clothing is contaminated, it should be removed carefully so that the contaminant does not become airborne; the contaminated clothing should be placed in a large impervious (e.g. plastic) bag and the bag sealed carefully. Areas of the body surface showing contamination should be demarcated. Hands and face are the areas most likely to be contaminated. During monitoring, search should be made for any abrasions, or wounds on the skin, since radioisotopes can be easily absorbed through such openings. Such openings in the skin should be masked with the aid of waterproof dressings.

If the contamination is limited to a small area, e.g. hands or face, it is usually adequate for the decontamination attendant to wear an apron and surgical gloves. If the contamination is widespread and heavy, complete surgical clothing and mask should be worn. Heavy contamination to a degree sufficient to cause a radiological risk to the examining physician and medical attendants is, however, an extremely rare event; such a contamination took place in a nuclear reactor accident once and radiation shielding and other precautions were taken by the examining physician to protect himself against the high intensity of external radiation emitted by the casualties. In the vast majority of cases, the levels of contamination will be far less than those reported in the above accident, and the risk may be, the transfer of contamination through handling of the patient or through inhalation of radioactive material which might become airborne. Treating the patient as though he is infected and adopting the standard barrier nursing techniques will help to minimise the radiological risks to the decontamination personnel. It should be ensured that no one other than authorised persons is allowed into the patient decontamination room.

2.5.2 DECONTAMINATION PROCEDURES -- GENERAL[28]

A schematic of medical management of external contamination is shown in Fig. 2.5.1. The decontamination procedure should be gentle and all care should be taken to avoid injuring the skin which can facilitate uptake by blood and systemic absorption of the contaminant. Contamination should be removed first from body orifices, particularly around nose, by dry wiping with paper towels, followed by dry wiping of other areas and then wet wiping of all areas. All wipes should be preserved for radioactivity measurements by the health physicist.

Decontamination should always be carried out starting from the periphery of the contaminated area and working towards the centre. Decontamination is simple in the case of loose superficial contamination on normal healthy skin. The radioactive material is usually trapped in the thin film of oil which covers the epidermis. The decontamination procedure aims at removal of this oil film by means of acid soap or mild detergent and water. Washing with soap/ detergent should be continued for 2-3 minutes. The area is then dried and monitored.

Decontamination is more difficult if the patient has thick dry horny and cracked skin or if the contaminant is deeply ingrained. If soap/detergent and water fails to remove the contaminant, 1% cetrimide solution can be used in the same manner as soap/detergent and water. A useful decontaminating agent is 5% sodium hypochlorite which should be used full strength on the skin except in case of areas around eyes and on the face where a 5:1 dilution with water is usually made before use. If the contaminant is not removed by the procedures described above, apply gently a saturated solution of $KMnO_4$ + 0.2N H_2SO_4 to the contaminated area of the skin. After drying, wash the skin with water. The stains on the skin left by $KMnO_4$ can be removed by applying a solution of 5% $NaHSO_4$. Care should be taken that the solution does not remain in contact with the skin for more than two minutes. Wash the skin, dry and monitor. Alternatively, the skin may be carefully scrubbed with cetrimide solution after local anaesthesia with 4% xylocaine or lignocaine. If erythema develops, the decontamination procedure should be stopped and the involved area covered with a lanolin containing cream and dressing. Next day, if the condition of the skin is improved, further attempts at decontamination may be made. It should be noted that the epidermis renews itself in 12-15 days and sometimes the contaminant which is very difficult to remove by physical or chemical means, will be shed along with the dead cells on the epidermis.

If the above methods fail and the contamination level remains extremely high, the contaminant may have to be removed surgically. Split skin removal may serve the purpose. In rare cases full thickness skin may have to be removed, followed by skin grafting.

Hair and scalp: If hair and scalp are contaminated, 4% cetrimide solution can be used for shampooing the hair, followed by rinsing with water. Care should be taken while rinsing, to ensure that the contaminant does not get into the eyes, nose or mouth. In some cases the hair may have to be clipped to remove the contaminant.

Eyes: Decontamination of eyes is best done in the first-aid post within the laboratory, facility or installation. A properly designed eye fountain should be available for washing the eyes. The eyes should be irrigated profusely with water.

Nose: The patient may be asked to nose blow by compressing his nose on to a tissue paper held close to the nostrils or the nostrils can be cleaned by nasal swabs. The nose can then be washed with isotonic saline. The nasal swabs or tissue samples should be kept for radioactivity measurements by the health physicist. Nasal irrigation is possible only after hospitalisation of the patient.

2.5.3 DECONTAMINATION OF BURNS AND WOUNDS

Cases of chemical/thermal burns and wounds must be referred promptly to the decontamination centre where they can receive medical attention from properly trained medical personnel.

Chemical and thermal burns may facilitate the entry of the contaminant into the body, although systemic absorption of the radioactive material is not so likely as in the case of open wounds. Decontamination should be as gentle as possible so as not to cause further breakdown of the skin. Pain during the decontamination can be alleviated by application of topical anaesthetics. In the case of nitric acid burn, the contaminant gets incorporated into the scab and decontamination becomes extremely difficult. In such circumstances it is probably best to cover the area with an impervious dressing with the hope that the contaminant would ultimately come off with the scab.

In the case of burns produced by Na or Na-K, liquid paraffin must be poured immediately over the affected part so as to cover the whole area. Visible pieces of metal may be removed by wiping gently with cotton wool or gauze. Splashes on the faces should be wiped away from the eyes, nose and mouth. If the patient is wearing protective goggles, they should be held tightly until the face is clean; the patient should close his eyes while the goggles are being removed. If a splash enters the eye, the eye should be irrigated promptly with liquid paraffin. The eyes may have to be held open by a third person since the patient will be unable to keep them open because of intense pain in the eyes. First aid given promptly is more valuable than prolonged irrigation later on,because the damage to the eye increases with every minute of contact of the strong alkali with the eye.

Wounds: The wound should be monitored carefully to determine the nature and quantity of radioactive material in the wound. The necessity for surgical intervention will depend upon the nature and quantity of radioactive contaminant.

If the material is soluble, it may be taken by blood rapidly and may enter systemic circulation. Measures are required to block systemic absorption and to hasten the elimination of the radionuclide from the body. If the material is insoluble, it may migrate along the lymph channel into the regional lymph node, the contaminant may then move on into the thoracic duct and enter systemic circulation. Treatment of internal contamination, including measures for blocking systemic absorption and hastening elimination of the contaminant from the body, are discussed in Section 6 of this Chapter.

All loose material around the wound should be removed. The contaminated wound should be isolated from clean skin by plastic drapes. Irrigate the wound with sterile water or saline and encourage bleeding by occluding the venous return to the area with a tourniquet. It may be necessary to enlarge the wound for more effective irrigation. If this treatment is not successful, a block of tissue containing as much of the contaminant as possible may have to be removed. The wound site and any tissues removed from it should be carefully monitored. It should be borne in mind that the objective of the decontamination is to minimise the long-term radiological risks to the patient. Care should therefore be exercised not to mutilate the anatomical structures. It is better to preserve function and cosmetic appearance than to ensure that all contamination is removed.

Metallic contaminants embedded in the skin may be removed by surgical excision. All the surgical instruments used for the decontamination of burns/wounds should be monitored and cleaned to ensure that they are free of residual contamination before they are used on other persons. Nose blow or nasal swab samples,tissues used for dry/wet wiping of skin surfaces, dressings, biological samples (exudate, blood, biopsy, scab) should be handed over to the health physicist for radioactivity measurements. The patient should be asked to submit urine/stool samples or referred to whole-body radioactivity monitoring, for assessment of internal contamination. The personnel decontamination room should be monitored and cleaned up.

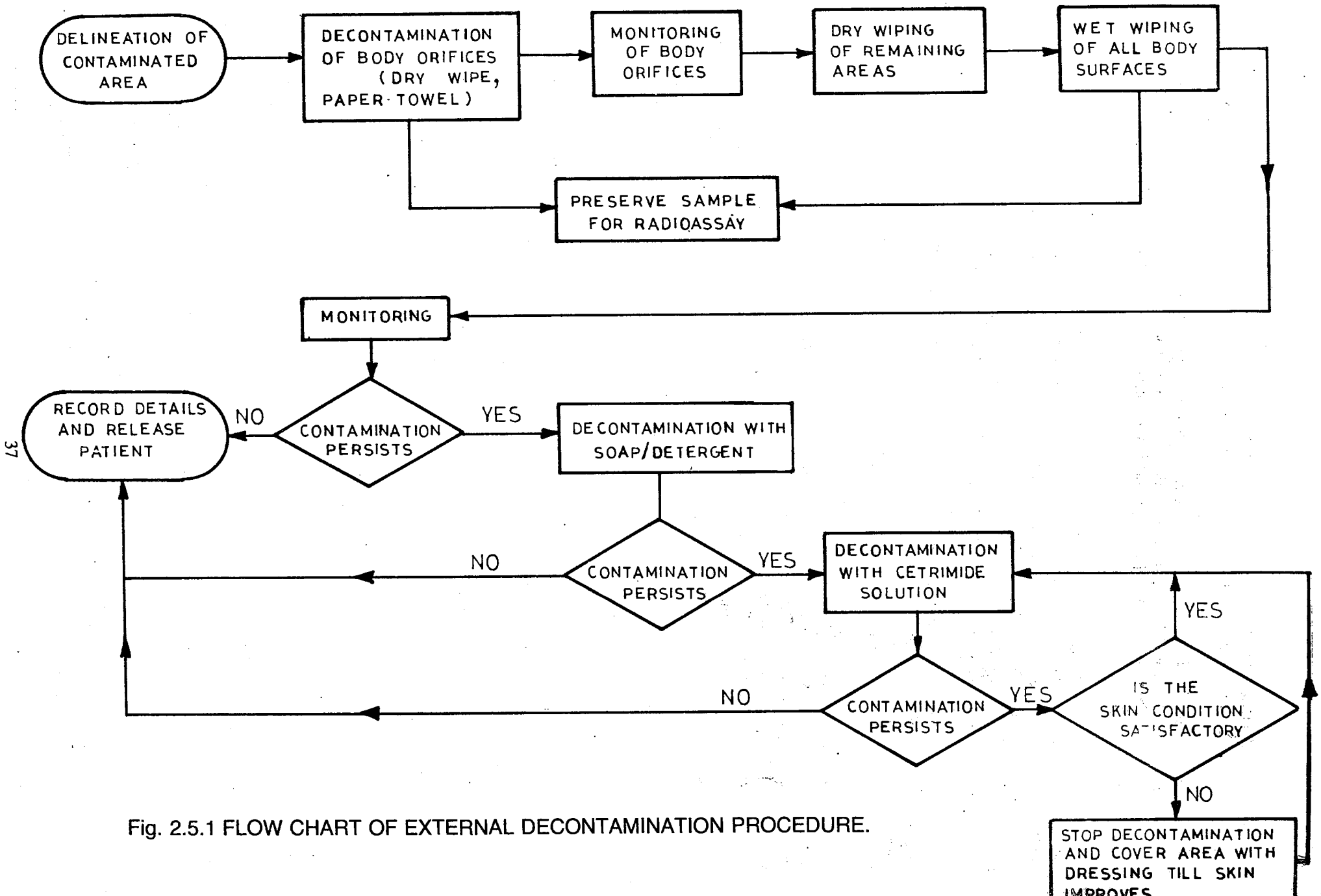

Fig. 2.5.1 FLOW CHART OF EXTERNAL DECONTAMINATION PROCEDURE.

2.5.4. DECONTAMINATION PROCEDURES: SPECIFIC

Uranium: The contaminated area of skin may be washed with $NaHCO_3$ solution.

Alkalies and Alkaline Earths: Washing with water should remove the contaminant in most cases. In the case of Sr, an attempt may be made by dabbing potassium rhodizonate crystals over the affected part. This renders Sr soluble which can then be washed away easily. (Note: The solution of potassium rhodizonate in water is unstable even if it is kept in a refrigerator).

Fission Products, Rare Earths, Plutonium and Transplutonics: Wash the skin with 1% DTPA solution (pH 3-5). Rub gently starting from the centre of the contaminated area and working towards the periphery. If DTPA is not available, EDTA or aqueous HCl solution (pH~1) can be used. Repeat as many times as required but stop if there is hyperaemia of the skin. (Note: In case of wound contamination with Pu or transplutonics, administration of DTPA i.v. has been recommended before irrigation of the wound with DTPA. The patient may get a burning sensation when DTPA is applied to the wound; this pain can be alleviated with topical anaesthetics).

Iodine: Iodine is rapidly absorbed through the skin. Give the patient potassium iodide (130 mg) in a little water. This will help to block thyroidal uptake of radioactive iodine. The blocking is more effective if it is given promptly after the contamination.

2.5.5 AMPUTATION

In very rare instances where an extremity is severely contaminated and adequate decontamination is not achieved, the surgeon may face the issue of whether or not to amputate the part. Unless the part is so severely injured that functional recovery is unlikely or extensive and severe radiation induced necrosis can be expected, amputation is seldom indicated. Conservative treatment should be tried first and the decision regarding amputation of the part must be postponed until the radiological risks are clearly defined.

SECTION 6

Radioactive Contamination : Internal

2.6.1 GENERAL

Internal contamination may occur due to accidental intake of radioisotope(s) through (a) inhalation, (b) injection, (c) ingestion or (d) absorption through intact or broken skin. The radiological risks to the patient depend upon (i) the amount of radioisotope, (ii) the mode of intake and (iii) the physical properties (e.g. physical state, type and energy of radiations emitted) and chemical form of the radioactive material which influence its biological behaviour within the body. The elimination of the radionuclide is defined by "effective half life" of the radionuclide in the body. The effective half life (T_{eff}) depends on the radioactive half-life (T_r) of the radionuclide and the biological half life (T_b) of the radionuclide in the body.

$$T_{eff} = \frac{T_r T_b}{T_r + T_b}$$

If the two half lives differ very much, T_{eff} is approximately equal to T_r or T_b, whichever is less. If the effective half life of a radionuclide is very small (minutes-hours), the radiation doses to the tissues and the radiological risks to the patient would be correspondingly very small. In such cases, it may not generally be necessary to consider internal decontamination measures. It should be noted that the behaviour of a radionuclide, particularly its dissolution in body fluids, may be influenced by the bulk matrix in which it is present.

Only in very rare instances such as accidents in nuclear reactors, fuel reprocessing plants or high level waste treatment facilities, where the inventory of radioactive materials is very large, or through therapeutic administration, a large amount of activity (> 10 MBq) may be taken into the body. In such cases non-stochastic effects (described in Section 2 of this Chapter) may be produced in the tissues, particularly along the route of entry (lungs, GI tract). It is most unlikely that internal contamination will pose any immediate threat to the patient's life. In the majority of cases of internal contamination the amount of intake may be generally low (< MBq) and carcinogenesis is considered to be the major radiological risk to the patient. The objective of internal decontamination is to reduce the risk of such late effects.

Inhalation is the most common mode of accidental intake. *Injection*, i.e. through puncture wounds may occur while manipulating radioactive substances with sharp edged tools, particularly in radiochemical laboratories and advanced fuel fabrication facilities. *Ingestion* may take place due to non-observance of safety procedures, e.g. mouth pipetting of radioactive liquids instead of using pro-pipettes, failure to check contamination of hands while leaving from active areas. Radioactive vapours e.g. tritiated water vapour in pressurised heavy water reactors (PHWRs) and radioiodine are absorbed through the intact skin, even if protective clothing e.g. plastic suit is worn, if the duration of exposure is long (hours).

Internal contamination involves four successive stages[29]

(a) Deposition along the route of entry.
(b) Translocation, i.e. movement from the site of deposition to blood or lymph.
(c) Uptake in organ or tissue.
(d) Clearance from the body.

The routes of entry of radioactive material into the body include respiratory tract, gastro-intestinal tract mucosa, skin and wounds. Of these the respiratory tract is most common and important route for radioactive aerosols. The deposition in the respiratory tract depends on the particle size of the aerosol. For particles of larger size, deposition is most likely to occur in the ciliated airways of nasopharynx and the large bronchi. Ciliary action removes the majority of the inhaled particulates to the pharynx from where it is subsequently transferred to the intestinal tract. The rate of

clearance depends on the site of deposition. Clearance from the trachea takes only a few minutes compared to several hours from the smaller distal airways. During this period of clearance the radioactive component of soluble particles may dissolve and translocate to blood through the airway epithelium. Insoluble particles reach the throat and mouth essentially unchanged and are subsequently swallowed.

For particles of smaller size, deposition takes place in the lung parenchyma. Soluble material deposited in this region dissolves in the lung surfactant, while insoluble particles are rapidly engulfed by alveolar macrophages. Clearance of this insoluble material depends on two processes: (a) dissolution of the particles in the intracellular fluids of the macrophages, the released fraction being transferred to blood, and (b) mechanical clearance of the particle-laden macrophages by muco-ciliary mechanism once they reach the ciliated epithelium of the airways.

The radioactive component of soluble compounds quickly translocates from the pulmonary region to blood but it takes several tens and hundreds of days respectively for this process to occur with moderately soluble and insoluble compounds. Some portion of the radioactive material which remains in the lung parenchyma is translocated along the lymphoid channels to the regional lymph nodes in the mediastinum.

Fig 2.6.1 shows a representation of the compartment model adopted by ICRP to describe the deposition of inhaled radioactive aerosols and clearance from different sections of the respiratory system. Table 2.6.1 gives the deposition fractions for the different compartments and the half-times for clearance from these compartments by different processes (represented as sub-compartments in Fig. 2.6.1).

Ingestion of radioactive materials is relatively rare as a primary mode of intake but in all cases of inhalation there is a secondary component due to the muco-ciliary transport mechanism and subsequent swallowing of the radioactive material. Fig. 2.6.2 shows the model of gastro-intestinal tract and Table 2.6.2 shows the clearance half-times of ingested radioactive material through different sections of the gastro-intestinal tract, according to the model of the digestive system adopted by ICRP.

All radioactive materials can be roughly classified on the basis of their biological behaviour into two categories: (a) transportable and (b) non-transportable[30]. This classification is highly schematic and the division between different compounds of a radioactive element is more apparent than real. The radioactive materials that are described as "transportable" are soluble in biological material and are able to diffuse throughout the organism; the entire deposit may pass fairly rapidly through the metabolic pathways, leading to deposition in target tissue(s)/organ(s). They are usually present in the organism in the physiological form either with a stable isotope (e.g. iodine) or a chemical analogue (e.g. caesium-potassium, strontium-calcium complex). These are capable of passing through the digestive tract.

The elements which are described as "non-transportable" (i.e. do not diffuse through the body) either because they are "insoluble" at all pH levels or are soluble only at acidic pH. In the latter case, they are hydrolysed as the pH rises, producing hydroxides which are polymerised on the spot. A small quantity of the contaminant is then absorbed depending on the degradation of the polymer which is a slow process. For such elements the important target tissues are liver and the bone surface. In the organism they are present in a complex which is stable and soluble. They are chelatable and can be redirected during their passage in blood towards elimination through the kidneys, thereby avoiding prolonged deposition in liver or bone surface.

It should be noted that 'solubility' is relative; the pH and redox potential of the medium vary, depending on the tissue. Thus an inhaled material may be insoluble in lung but absorbable in stomach if it dissolves in the stomach acid. Conversely a soluble material may be made completely insoluble in the digestive system by alkalinization in duodenum, leading to formation of insoluble hydroxides.

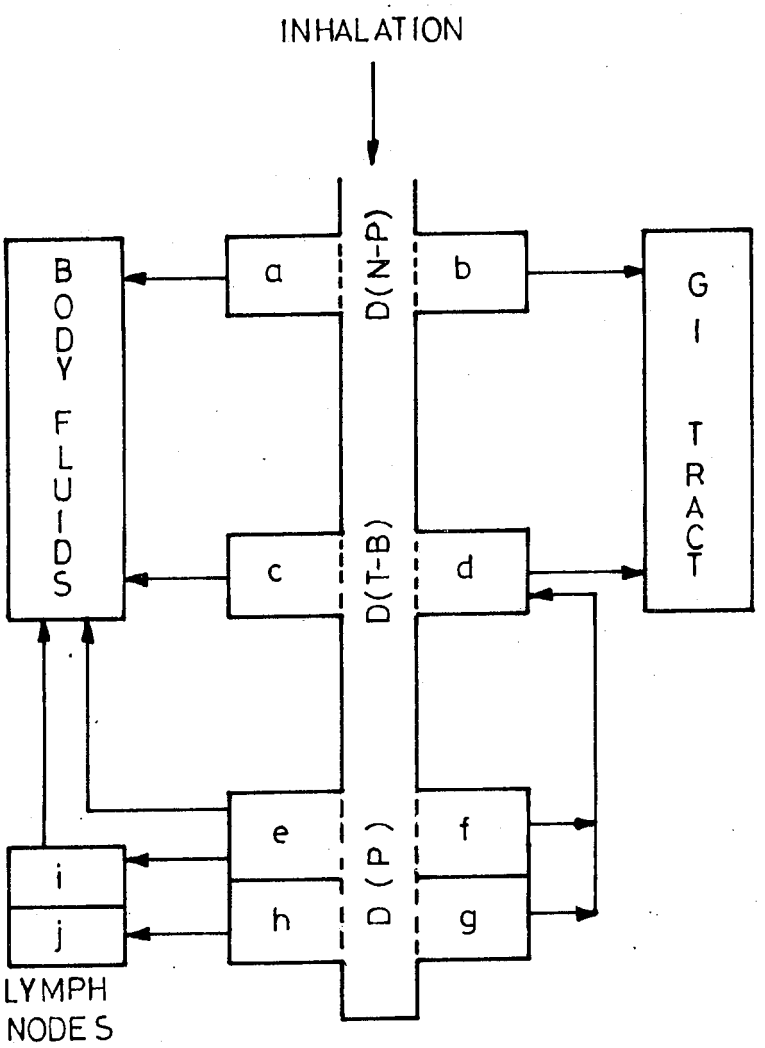

Fig. 2.6.1. MATHEMATICAL MODEL USED BY ICRP TO DESCRIBE CLEARANCE FROM THE RESPIRATORY SYSTEM. FRACTIONS a TO j ABSORBED FROM DEPOSITIONS IN NASOPHARYNX, D(N-P), TRACHEO-BRONCHI, D(T-B) AND PULMONARY REGION, D(P) ARE SHOWN IN TABLE 2.6.1.

TABLE 2.6.1 DEPOSITION FRACTIONS AND CLEARANCE HALF TIMES
(Respiratory System)

		Class					
		D		W		Y	
Region	Compart-ment	T day	F	T day	F	T day	F
N-P	a	0.01	0.50	0.01	0.1	0.01	0.01
(D_{N-P}=0.30)	b	0.01	0.50	0.40	0.9	0.40	0.99
T-B	c	0.01	0.95	0.01	0.5	0.01	0.01
(D_{T-B}=0.08)	d	0.20	0.05	0.20	0.5	0.20	0.99
	e	0.5	0.80	50	0.15	500	0.05
P	f	n.a.	n.a.	1.0	0.40	1.0	0.40
(D_P=0.25)	g	n.a.	n.a.	50	0.40	500	0.40
	h	0.5	0.2	50	0.05	500	0.15
L	i	0.5	1.0	50	1.0	1000	0.9
	j	n.a.	n.a.	n.a.	n.a.	Infinite	0.1

The values for the removal half-times, T_{a-i} and compartmental fractions, F_{a-i} are given in the Table for each of the three classes of retained materials. The values given for D_{N-P}, D_{T-B} and D_P (left column) are the regional depositions for an aerosol with an AMAD of 1μm. The schematic drawing in Fig 2.6.1 identifies the various clearance pathways from compartments a-i in the four respiratory regions, N-P, T-B, P and L. The radionuclides are grouped into three classes, viz D,W or Y depending on whether their clearance from the respiratory system takes place within days, or weeks or years.

TABLE 2.6.2 CLEARANCE HALF-TIMES

(Gastro-intestinal System)

Section of GI tract	Mass of walls* (g)	Mass of contents* (g)	Mean resi-dence time (day)	λ day^{-1}
Stomach (ST)	150	250	1/24	24
Small Intestine (SI)	640	400	4/24	6
Upper Large Intestine (ULI)	210	220	13/24	1.8
Lower Large Intestine (LLI)	160	135	24/24	1

*From ICRP Publication 23(1975).

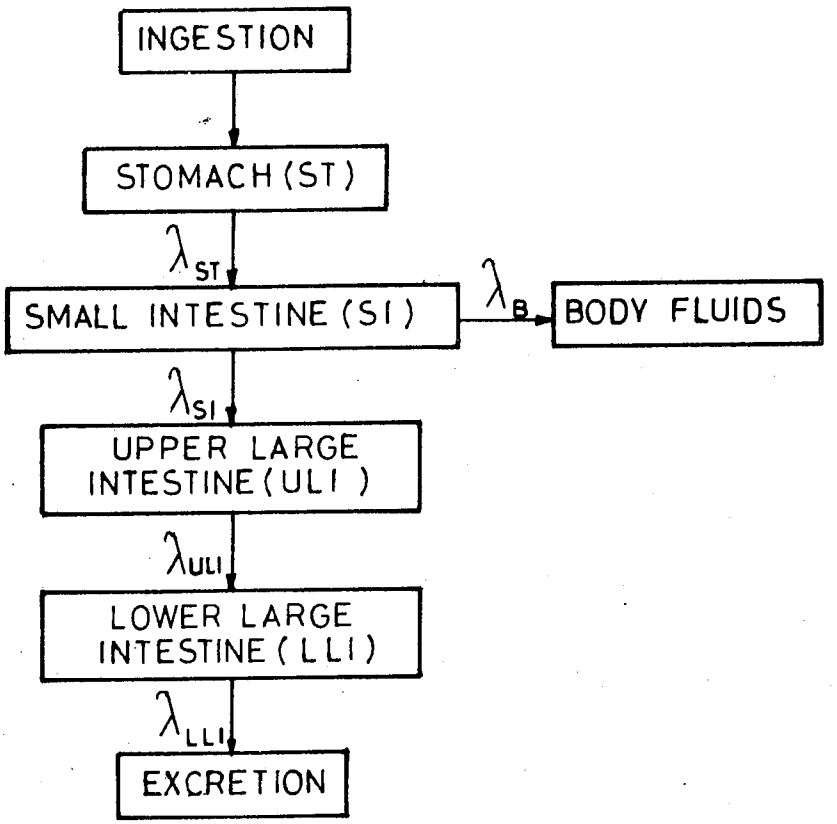

Fig. 2.6.2. MATHEMATICAL MODEL USED TO DESCRIBE THE KINETICS OF RADIONUCLIDES IN THE GASTROINTESTINAL TRACT.

There are two distinct mechanisms for clearance, either directly by excretion of the radionuclide in the blood through the kidneys or indirectly when radionuclide in tissue is reabsorbed into blood after reversal of target tissue/ blood concentration ratio. Since there is a balance between blood and the excreta, it is possible for the radionuclide to be eliminated from the organism. These two mechanisms may coexist to a variable degree, depending on the radioactive element.

Theoretically treatment can be aimed at any of the four stages mentioned earlier. However, the two most effective methods of treatment are blockage of tissue uptake, either fixing the radionuclide at the site of entry [stage (a)] or by trapping it in blood during translocation [stage (b)] and re-routing it towards a natural excretory mechanism. Action at stage (c) is possible in the specific case of radioactive iodine and thyroid gland. Action at stage (d) is generally ineffective, except for tritium which can be flushed from the body by administration of excess fluids.

From the foregoing it will be abundantly clear that treatment of internal contamination, if it is to be effective, must be given promptly, preferably in a first-aid post attached to the plant, facility or laboratory. The effectiveness of on-the-spot treatment decreases rapidly with time. It is all the more important to deal with the contaminant at the point of entry into the body, particularly in the case of those elements for which therapy is not effective once they are absorbed in the system. Deposition commences in the target tissue(s) as soon as the radionuclide is translocated to blood and every moment wasted increases the tissue deposition almost irrevocably. Therefore, the urgency of treatment is applicable even in the case of radioactive elements which are amenable to treatment at blood level [stage (b)] or by preliminary blocking of deposition in the target organ [stage (c)].

First aid to persons involved in a radiation accident should be given merely on the presumption of contamination. First aid, even without definite diagnosis is preferable to no first aid at all, provided that it does not involve undue hazard. In cases of internal contamination accompanied by traumatic injury, the first aim must be to save the life and preserve the vital functions of the patient. Treatment of the contamination comes only second. The medicaments used for first aid should be administered at non-toxic doses, as preplanned by the physician in charge of the facility. To expedite the treatment, it is desirable for the contaminated person to self-administer the first aid. For example, administration of stable iodine to block the thyroid or local application of chelating agent such as DTPA to a wound contaminated with plutonium or transplutonics. The mode of application should be simple and confined to local application, ingestion or inhalation of aerosol.

Medico-legal problems may arise regarding self-administration of first-aid by the contaminated person. These difficulties can be overcome in several ways:

1. Using simple products for external application wherever possible.

2. By entrusting the responsibility to persons trained in first-aid procedures, and who can assess the seriousness of the radioactive contamination.

3. By limiting the amounts of drugs available for internal use (e.g. 50 mg of aerosol DTPA ready for use instead of the usually prescribed 1g).

After administration of first-aid at the plant, laboratory or facility, the patient should be promptly referred to the site decontamination centre, where he can receive further medical attention from trained medical staff.

At the site decontamination centre, the patient should be given first-aid treatment in case it has been omitted at the plant, laboratory or facility (e.g. because of traumatic injury). The samples required for a definite diagnosis of the contamination (e.g. mucous from nose, blood, urine, stool) as well as other appropriate samples for later clinical examination should be collected. The patient should then be checked for external contamination and if any is detected, he should be decontaminated. The patient may then be referred for monitoring of internal contamination. Treatment may be continued or modified, if found necessary.

2.6.2 EXCISION OF CONTAMINATED WOUNDS

Cases with contaminated wounds should be referred promptly to the site decontamination centre. The severity of the injury and the degree and type of contamination should be kept in mind. Treatment of the radioactive contamination depends on whether the contaminant is transportable or not. If it is transportable it should be made insoluble at the wound site, if possible, to prevent systemic uptake. It may be necessary to consider surgical excision

at a later stage if monitoring with a suitable wound probe indicates a high level of residual fixed contamination. Treatment of injury takes precedence over treatment of internal contamination. The patient should be then referred for monitoring of internal contamination and decisions should be made regarding continuance of medical treatment based on the results of such monitoring.

If the contamination is non-transportable, the injury can be treated with a topical therapeutic agent (e.g. chelating agent), before considering surgery. In case of radioactive metallic objects or solid particles, surgery may be the only way to remove the contaminant. Surgery is usually not urgent and can wait until the surgical team is organised. During surgery, it is necessary to monitor the residual contamination in the wound at frequent intervals and to check contamination of gloves and surgical tools using a suitable wound probe. The surgical instruments and possibly the gloves, may need to be changed to avoid spreading of contamination. These requirements may tend to delay the operation. Such delays become important when the surgery involves a tourniquet, for which there is always a time limit.

A conventional operating room is suitable provided it is not too cluttered and can accommodate the staff and monitoring equipment and can be easily monitored. The operating table, other tables, floor etc. should be covered with disposable plastic.

The normal arrangements for asepsis are adequate for protection of the staff against radioactive contamination. Provision should be made for a large-area detector within the reach of the surgeon so that his gloves and surgical instruments can be continuously monitored. In case of alpha contamination, personnel monitoring badges are not required. If the contamination is very high it may be necessary for the surgical team to wear respirators.

There is generally no risk of contamination of anaesthesia and breathing equipment even in cases of patient with contamination of lungs. It is only the components that come in direct contact with the respiratory passages that may become contaminated. The mucous extractor may be fitted with a protective container which can be passed on later for radiochemical analysis.

The equipment required for surgery would be the same as in conditions where there is no radioactive contamination, but may be arranged atleast in triplicate. If the wound is to be washed, it is useful to add one ampoule of DTPA per 100 ml of washing solution. If anaesthesia requires perfusion an ampoule of DTPA may be added.

A suitable detector should be provided to monitor excised tissue. The tissue samples may then be kept in plastic bags for more exact measurements later on. There should be adequate supply of compresses and plastic bags.

Surgery should be conducted with frequent monitoring of the wound site and a decision should be made when to stop further surgery in consultation with the health physicist. Mutilation from extensive surgery should be avoided.

Amputation should not be carried out purely on the radiobiological considerations during initial surgery. The consideration of secondary surgery and possibly amputation should await detailed consultation on dose commitment and long-term radiological consequences from contaminated tissue.

All contaminated plastic sheets and other disposable supplies should be placed in impervious, water-proof bags and sent for disposal. Non-disposable items such as surgical tools and instruments should be decontaminated and monitored before returning them for reuse.

2.6.3 DECONTAMINATION OF RESPIRATORY SYSTEM

It is generally difficult to evaluate intakes of radioactive material through inhalation. The first aid treatment should be given even in cases of slightest suspicion of intake through inhalation. In the case of radioactive noble gases (particularly short-lived beta emitters) first-aid therapy may not be of any value since the gases cause external irradiation of the epithelium in the airways. In the case of radioiodine, thyroidal uptake should be blocked by oral administration of stable iodine. In case of plutonium and transplutonics, DTPA aerosol should be administered by means of an aerosol inhalation system [cf Photograph 8 in Plate-II] or a "spinhaler" [cf Photograph 9 in Plate - II]. Nasal swabs or nose blow samples should be collected from the patient to obtain an initial estimate of the extent of contamination through inhalation. The patient should be monitored for external contamination, decontaminated if required, and referred to the decontamination centre for attention by trained personnel.

Upon arrival at the decontamination centre, the patient should be given first aid treatment in case it was omitted

at the place of accident. If the nose blow or nasal swab samples do not indicate serious contamination the patient should be referred for lung counting. He should be asked to submit urine/stool samples for radiochemical analysis. It should be borne in mind that the lung normally clears inhaled products to varying degrees and one of the pathways of clearance is the digestive tract. Clearance through the digestive tract may in fact involve a large fraction of the total amount of the contaminant--particularly of the larger sized particles. Therefore, there may be secondary absorption from the digestive tract. It is thus essential after an accident involving high degree of contamination of lungs by a radionuclide which is also absorbable in the digestive system to render it insoluble in the gastrointestinal tract. In the case of beta emitters irradiation of the mucosa can be reduced by administration of a fast acting laxative or a phosphosoda enema. Based on the results of internal-contamination – monitoring decision may be made regarding follow-up medical treatment.

Pulmonary Lavage

In case of non-transportable radioactive material, particularly plutonium, pulmonary lavage is the only possible treatment. It has been used once in a human case for reducing the amount of $^{239}PuO_2$ in the respiratory system. This is a highly specialised and complex procedure and it carries a certain amount of risk to the patient. The decision to try out this procedure must be made by a qualified specialist after weighing the pros and cons. The indication for the procedure depends on the lung burden and the age of the patient. Since the main risk from contamination is lung cancer with a latent period of possibly several decades, it may be prudent not to consider this treatment for older patients. In the case of young patients, considering the uncertainties involved in estimation of lung burdens, it is difficult to establish indications for this treatment except in very extreme cases. Although some workers have suggested an intervention level of 50 MPLB (Maximum Permissible Lung Burden) for patients under the age of 30 years, a more cautious approach would be to consider the procedure at a level of 100 MPLB or more. The clinical indication for the procedure should be clearly established based on the lung picture by the physician, surgeon and anaesthetist. Besides the contamination level the age of the patient should be taken into consideration.

The initial lavage can be carried out after the second or third day. It can then be repeated twice a week for two weeks and then once a week upto a total of ten lavages. If possible, the lungs should be washed within an hour. Additional lavages of both lungs may be done at intervals of 3-4 days.

An intubation equipment (e.g. Carlen's probe) is required. Normal physiological saline (9g NaCl/litre) is used as the washing fluid. DTPA (1g/litre) can be added to the washing fluid.

The normal lung volume is 0.5 litre. One lung is filled with the washing fluid to a pressure between 20-25 cm H_2O. This can be done with a syringe fitted with a manometer or with a container placed higher than the patient. The washing fluid is then drawn out of the lung with a syringe or allowed to drain out by gravity; in the latter case the operation is facilitated if the patient's head is kept in an inclined position.

The optimum number of irrigations is about six. The duration of irrigation is about 3 minutes. The washing fluids should be retained for histological and radiotoxical testing. The different washings should be properly identified.

No rigorous guidance can be given regarding termination of the trials but the contamination level, effectiveness of decontamination, loss of effectiveness with time, physical and psychological tolerance of the patient are all taken into account.

2.6.4 DECONTAMINATION OF GI TRACT

Radioactive material may enter the G.I. tract directly through swallowing from mouth and indirectly through transport from respiratory system by muco-ciliary clearance to pharynx and subsequent swallowing. If the material is non-transportable and insoluble in gastro-intestinal tract, only a small fraction would be absorbed into the system and the major portion would be eliminated through feces. The small fraction that is absorbed may not usually require treatment. If the material is transportable and absorbable in the digestive tract, absorption takes place with subsequent deposition in other tissues. Attempt should be made to render it insoluble and prevent systemic absorption. In some cases (e.g. Sr-90, Ca-45, Cs-137) the material may remain in the intestinal epithelium which would be irradiated. The irradiation will be greater if intestinal stasis is present.

If the patient is suspected to have swallowed radioactive material, he should be referred immediately to the site decontamination centre. At the site decontamination centre, decontamination should be done as soon as possible without waiting for internal contamination monitoring procedure which can be conducted later. Immediate general treatment may be carried out along the following lines:

(1) If much time has not elapsed after ingestion, the stomach can be emptied or an emetic can be given to the patient. The stomach washings or vomitus should be collected in a suitable receptacle to avoid contamination of surfaces and equipment.

(2) A catharsis should be given to cause bowel movement and reduce irradiation of intestinal epithelium.

(3) The patient may be given a large amount of stable isotope of the same radionuclide or a chemically analogous element which would compete with the radionuclide and reduce its absorption in the intestines.

(4) Specific therapeutic agents such as ion exchange resins, insolubilising agents, gels and antacids may be useful in reducing intestinal absorption of the radioactive material and thus reducing the irradiation of intestinal epithelium.

Table 2.6.3 gives guidance on internal decontamination for different radionuclides using specific pharmaceuticals.

TABLE 2.6.3: SPECIFIC TREATMENTS USED FOR ACCELERATING THE REMOVAL OF SOLUBLE RADIONULIDES[31]

Material	Mode of action	Mode of administration	Element	Effectiveness	Comments
Ammonium chloride	Releases H^+ in renal tubules, favouring the formation of alkaline earth metal ions	2 g three times a day orally for 6 consecutive days with meals	Sr	*	May cause gastric irritation and vomiting. Contra-indicated in patients with liver disease and renal disease. Must correct acidosis in cases of over dosage.
Alginate	Forms a viscous insoluble gel in which metallic elements are absorbed.	10 g once or twice a day orally, reducing to 4 g a day.	Sr	+	May cause constipation
Barium sulphate	Forms insoluble sulphate with alkaline earth metals.	300 g orally in aqueous suspension	Sr, Ra	*	May cause constipation
Chlorthalidone	Acts as a diuretic preventing reabsorption of Na^+ in renal tubules	100 mg a day orally reducing to 50 mg a day	^3H, Na, K Ru	*	May cause dehydration, electrolyte imbalance, headache, gastric disturbances, skin rashes. Contra-indicated in persons sensitive to sulphonamides and in renal and hepatic insufficiency.
Desferrioxamine B	Chelates the radionuclide as a soluble complex that is excreted in the urine. Has a marked affinity for iron in the ferric (trivalent) state	1 g intravenously in istotonic saline or glucose (slowly), 8 g orally	Mn, Fe, Co	*	May cause tachycardia, hypotension, skin rashes, gastric disturbances, vertigo, convulsions. Contra-indicated in pregnancy (it has been shown to be teratogenic in experimental animals).
Dimercaprol	Chelates the radionuclide as a soluble complex that is excreted in the urine. The radionuclide molecule attaches preferentially to the metal through an -SH group.	2.5 mg kg^{-1} or less administered intramuscularly at 4-hourly intervals during the first 2 days, twice on the third day and once daily for 5-10 days.	Po, Au, As, Pb, Hg, Cr, Ni, Bi	*	May cause hypertension, techycardia, sickness, conjunctivitis. Deposition of metals in the kidney tubules has been reported.
Diethylenetriamine penta acetic acid, DTPA (as Ca or Zn salt)	Chelates the radionuclide as a soluble complex that is excreted in the urine. The radionuclide molecule attaches to the metal through O-or N-groups	0.25-1 g intravenously to be repeated daily as required; or 1 g of aerosolised or inhaled microfine power	Transuranics Lanthanides Mn, Co, Zr, Ru.	+ + *	May cause diarrhoea. Contra-indicated in renal diseases and where there is evidence of leucopenia. Contra-indicated for uranium unless given with sodium bicarbonate which prevents the deposition of insoluble uranium compounds in the kidney.

(TABLE 2.6.3 CONTINUED)

Material	Mode of action	Mode of administration	Element	Effectiveness	Comments
Frusemide	Acts as a diuretic; prevents reabsorption of Na in the loop of Henle	40-80 mg a day orally	Na, K, ^{3}H	*	As for chlorthalidone
Iodine and/or potassium iodide /iodate	The stable element acts as a blocking agent	130-300 mg potassium iodide orally immediately, repeated for 7-14 days; or 1 ml Lugol's iodine (50 mg iodine + 100 mg potassium iodide) orally per day for 7 days; or KIO_3 160 mg bd	I	+ +	After prolonged exposure, may cause swollen neck glands, rhinitis, conjunctivitis, headache, skin rashes in a small percentage of sensitive individuals. KIO_3 has long (3yrs) shelf-life.
Magnesium sulphate	Acts as a laxative, forms insoluble sulphates with Sr and Ra	10-15 g orally per day	Sr, Ra	*	Contraindicated in renal disease, bile duct obstruction and inflammation of the colon.
Metal gluconates	The stable elements act as isotopic diluting agents	Calcium salt 2.5 g in 500 ml glucose Saline intravenously; 6-10 g 3 times a day orally with meals.	Ca, Sr, Ba, Ra	*	May cause hypercalcaemia, vomiting and dehydration. Contraindicated in patients with renal disease and patients receiving digitalis.
		Strontium salt 0.6 g in 500 ml isotonic glucose saline intravenously; 0.15-1.5 g a day orally with meals.	Sr	*	No known toxicity
		Cobalt Salt 0.9 mg a day intramuscular or orally to be repeated as required.	Co	*	
Penicillamine	Forms a soluble amino acid chelate that is excreted in the urine.	0.25 g orally four times a day between meals	Cu, Fe, Hg, Pb, Au	*	May cause hyper-sensitivity reactions.
Prussian blue	Acts as an ion exchanger for some monovalent ions, thereby preventing their intestinal absorption	1 g (preferably in colloidal form) three times a day orally to be repeated for a few weeks as required.	Rb, Cs, Tl	+ +	May cause constipation. Dosages of upto 10 g per day in 3 divided doses have been used in case of Goiania, Brazil casualties[26]
Sodium bicarbonate	Forms a soluble complex with uranyl ion ($UO_2(CO_3)_3)^{4-}$) which is excreted in the urine	3.5 g in 250 ml of isotonic saline intravenously	U	+	May cause metabolic alkalosis and respiratory depression leading to pulmonary oedema. Contraindicated if electrolyte imbalance is already present.

Effectiveness
- * marginal
- + effective if given soon after intake
- + + very effective if given soon after intake.

CHAPTER 3

FACILITIES, EQUIPMENT AND TECHNIQUES

SECTION 1

Facilities

3.1 INTRODUCTION

Essential facilities and equipment must be provided for prompt assessment of radiation doses/contamination and for immediate care of persons involved in radiation accidents. Therefore, "First-aid Post" is needed at each installation and "Decontamination Centre" at each site. Depending on the size of the installation more than one First-aid Post may be required.

3.1.1 FIRST-AID POST

First-aid is required only in the case of contamination since the irradiation casualty will not generally require any emergency treatment. The governing principle in the administration of first-aid for internal contamination is that the first-aid treatment should be given merely on the presumption of contamination and that aid, even without sure diagnosis, is preferable to no aid at all, provided that it does not involve undue hazard. This underlying principle calls for implementation of this treatment, if possible, by the exposed person himself in order to reduce to the minimum the time between contamination and treatment. In any case, the treatment should be available at the first-aid post attached to the facility and the first-aid assistant or health physicist should be able to provide the first-aid.

FIRST-AID ROOM

A separate room, preferably close to the change room of the plant, should be designated for administering first-aid in the case of internal or external contamination. If possible, this room may be separate from the first-aid room for conventional injuries, not involving radioactive contamination. The room should have a minimum floor area of 5m x 5m. There should be a separate shower cubicle, wash basin supplied with cold and hot water and a hand drier. The floor and walls of the room should be painted with epoxy paint. The room should be equipped with the following: (1) Protective equipment kit, (2) Instrument kit, (3) Skin decontamination kit, and (4) Internal decontamination kit. The kits can be in the form of cupboards with glass front panels with the contents in each cupboard displayed outside in the form of a list.

Protective Equipment Kit

It should consist of: (1) four numbers of overall or laboratory coats,(2) six plastic aprons,(3) ten pairs of surgical hand gloves, (4) four pieces of skull caps (5) four pairs of cotton or plastic overshoes, (6) 10 numbers of plastic bags, and (7) 1 roll of polythene sheet.

Instrument Kit

It should consist of: (1) Battery-operated end-window G.M. contamination monitor - 2 Nos. Range up to 500 kcpm; (2) Battery- operated alpha scintillation monitor - 2 Nos. Range upto 500 kcpm; (3) Battery-operated contamination monitor with low energy gamma scintillator probe - 1 No; (4) Portable G.M. Survey meter with side-window probe and beta shield (0-20 mR/hr) - 2 Nos; (5) General purpose radiation monitor (0-5 R/hr); (6) Check sources, both alpha and beta-gamma, for testing of instruments; and (7) spare batteries.

Skin Decontamination Kit

It should contain:

1. Cotton applicators for nasal swabs		
2. Surgical cotton rolls		
3. Masking tape		
4. Felt pens for marking contaminated spots		
5. Brushes with soft bristle		
6. Triangular bandages, sterile	--------12	Nos.
7. Eye pads, sterile	--------10	,,
8. Melolin non-adherent absorbant dressings --large	--------20	,,
9. Paraffin gauze dressings	--------10	,,
10. Swabs 7.5cm x 7.5cm-pack of 200	--------1	,,
11. Crepe bandages 7.5cm x 4.5cm	--------12	,,
12. Nail brushes	--------5	,,
13. Nasal catheters	--------2	,,
14. Sterile water		
15. Sterile eye-wash solution		
16. Clippers with razors, shaving soap and brush		
17. Detergents		
18. Acid soap		
19. 5% sodium hypochlorite solution (2 litres)		
20 Saturated solution of potassium permanganate (1 litre)		
21. 0.2N H_2SO_4 (1litre)		
22. 5% $NaHSO_3$ solution (1 litre)		
23. HC1 solution pH 1 (1 litre)		
24. Sodium bicarbonate solution (1 litre) for Uranium		
25. DTPA ampoules (50 ampoules) for Pu and transplutonics		
26. Sample collection vials		
27. Adhesive labels.		

Internal Decontamination Kit

Ten separate kits, each comprising of: (1) 130 mg of KI for ^{131}I; (2) ten capsules of micronized powder of DTPA; (3) a simple aerosol generator for inhaling the contents of DTPA powder capsules (e.g. spinhaler) for Pu and transplutonics; (4) colloidal Prussian blue (1 g) now commercially available as Radiogardase for ^{137}Cs; (5) colloidal alginate for ^{90}Sr, ^{226}Ra (10 g) for alkaline earths, (6) potassium rhodizonate (1 g) for alkaline earth elements; (7) clear printed instructions for use of the above medicaments, and (8) blank forms of health physics report.

3.1.2 DECONTAMINATION CENTRE

The decontamination centre should be located at or near the "Site Hospital". It should be equipped to receive and treat, if required on inpatient basis, persons with persistent external or internal contamination. The area should be segregated from the rest of the hospital but should be self-sufficient in terms of carrying out minor surgery and other life-saving procedures. The layout of a typical facility of this type is shown in Fig. 3.1. The functions of the different areas are explained in the diagram. Such a facility should be established in consultation with a qualified health physicist. The facility should be capable of treating atleast ten affected persons on inpatient basis.

There should be separate entrances for the staff and the patients requiring attention. Patients may arrive either in ambulance or on a stretcher, if non-ambulatory. The staff enters through a change room. There is a separate office for the radiological safety officer and/or nurse. The clean side of the change room is equipped with lockers and cupboards containing protective equipment. The protective equipment includes sterilised surgical gowns, caps, masks, coveralls, surgical handgloves, cotton or plastic overshoes. The area has facility for keeping dosimeters. After changing, the staff enter the personal decontamination room. The contaminated side of the change room has receptacles for discarding contaminated clothing etc., showers and wash basin facilities, a barrier and radiation monitoring instruments both for alpha and beta radiations. There is a separate room for equipment and supplies. These are (i) skin decontamination supplies, (ii) internal decontamination supplies, (iii) radiation instruments and (iv) general drugs and medical supplies like dressings, splints etc. Insofar as skin decontamination and internal decontamination supplies are concerned, the provisions required in the first-aid post should be duplicated at the site decontamination facility. In addition, the following items should be added: (i) ten ampoules of DTPA (or 10 self-injecting syringes) containing 1 g per ampoule (4 ml), (ii)a box containing adequate quantities of material for nasal sampling, (iii) blood sampling tubes and sample bottles/pouches for urine/faeces and (iv)sampling backup supplies for continued treatment (can be

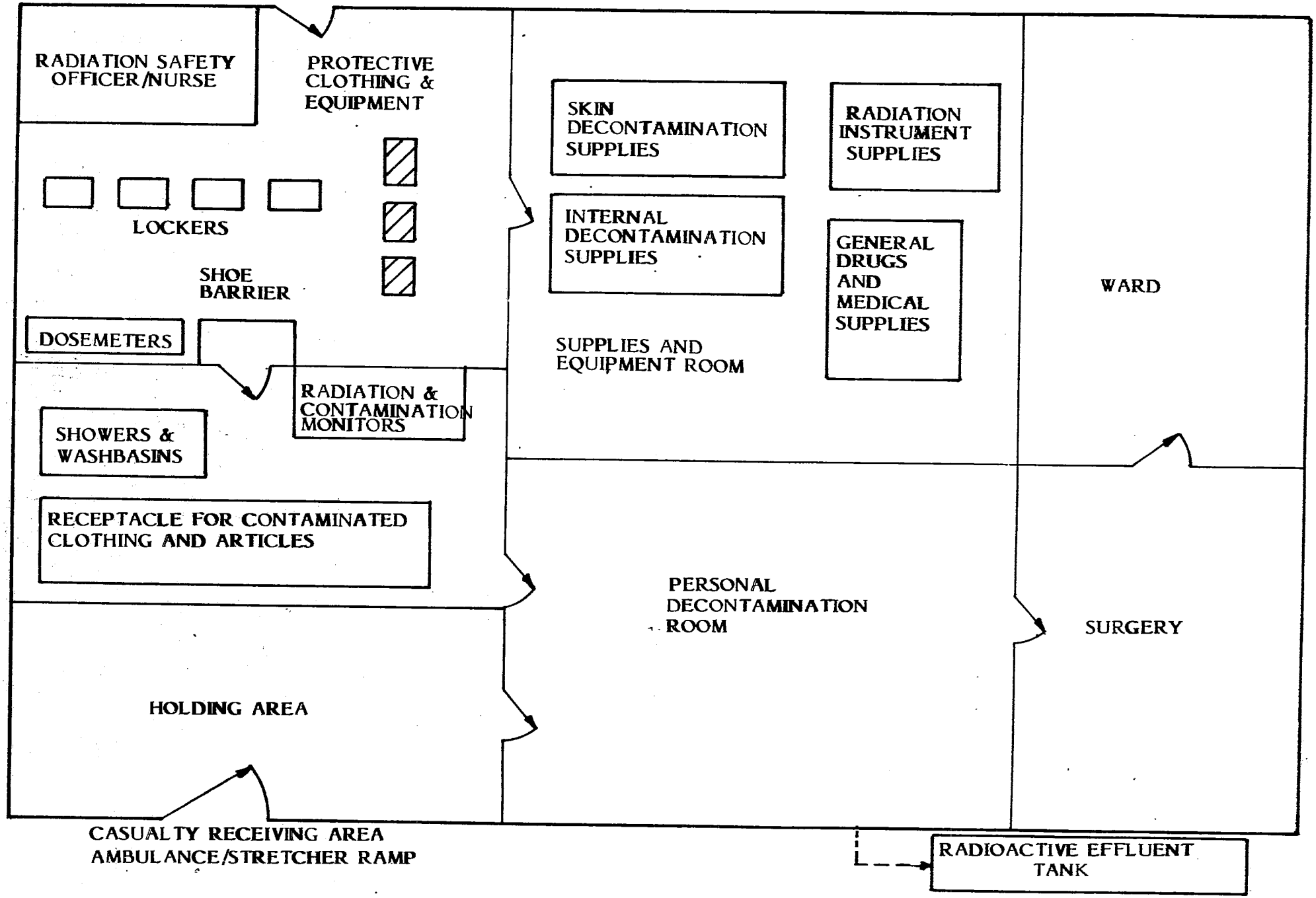

FIG. 3.1 LAYOUT OF SITE DECONTAMINATION FACILITY

drawn from the hospital's main store). The personal decontamination room should be equipped with a shower cubicle, wash basin and an operating table with drain facilities and flexible shower head for washing non-ambulatory patient. The surgery and ward are to be used exclusively for contaminated patients. There should be a sump where contaminated effluents can be collected.

3.1.3 SITE HOSPITAL

The site hospital should have a separate ward or wing for medical care of radiation casualties. It will be ideal if this ward/wing has an adequate number of single rooms which can be quickly converted into isolation rooms. The rooms should be provided with ultraviolet light for sterilisation of air. At the entrance to the room antiseptic door mats should be placed. A separate kitchen should be available for supply of sterile food to the irradiated patient. The hospital should have a blood bank and facilities to separate the different components such as RBC, platelets. The hospital should liaise with a laboratory for carrying out cytogenetic studies and with a BMT facility for HLA typing. The hospital should have all the drugs, mentioned in Chapter 2, for treatment of the irradiated patients and for radioactive decontamination. Adequate number of the nursing staff should be well trained in nursing care of irradiated patients.

SECTION 2

Clinical and Biological Dosimetry

3.2.1 GENERAL

An estimation of dose can be made on the basis of clinical observations as well as laboratory investigations of the exposed individuals. The latter includes haematological, cytogenetic, biochemical and neurophysiological examinations[32]. A combination of a variety of these clinical and biological dosimetric methods can provide reliable information regarding absorbed dose, dose distribution, time span of dose delivery, biological damage etc. Even though many biological indicators may be only qualitative or semi-quantitative, they are of considerable prognostic value. In view of the variation in the dose response among individuals and the presence of confounding factors such as intercurrent diseases, it is necessary to depend on a variety of biological endpoints to assess the functional impairment of individual organs and to evaluate the prognosis.

3.2.2 PRODROMAL EFFECTS

Following whole-body exposure,the prodromal response appears during the first 48 hours. These reactions result from the irritation of the upper intestines, causing anorexia, nausea, vomiting, diarrhoea, intestinal cramps, salivation, dehydration and neuromuscular reactions, resulting in fatigue, apathy, sweating, headache and hypotension[33,34]. The frequency of incidence of prodromal symptoms, the time course of their appearance and their persistence are dose-dependent. Whole body exposure to a dose of approximately 2 Gy results in 50% of the exposed individuals showing prodromal effects with an average latent period of 3 hours. Even though the individual variation in the latent period can be between 1 - 24 hours in the dose range 1 - 2 Gy, at higher doses above 4 Gy, the prodromal symptoms manifest within an hour following exposure. Further details of the kinetics of the dose dependence of prodromal symptoms, based on Chernobyl experience, are summarised in Table 3.2.1. Inspite of some uncertainties, the prodromal symptoms (particularly vomiting) serve as the earliest biological indicators of dose and hence are very useful for triage of the exposed individuals.

TABLE 3.2.1: SUMMARY OF CLINICAL FINDINGS AND PROGNOSIS IN MAN AFTER WHOLE BODY IRRADIATION
(Based on Chernobyl Findings) [24]

Approx. dose Gy	0.25-0.75	0.5-2	2.1-4	4.1-6	6.1-15	15.1-50	> 50
Time of onset of prodromal syndrome	0	2-24h	1-48h	0.5-1h	0.5h	0-0.5h	Immediate
Frequency of nausea and vomiting %	0	20-70	10-80	90-100	100	100	100
Blood picture							
Lymphocytes/μL	1500-3000	600-1000	300-600	100-500	<100	—	—
Granulocytes/μL	—	1500-2000	>600-1500	< 1000(8-20d)	<500(7-9d)	—	—
Platelets/μL (and nadir)	—	40000-60000 (25-28d)	40000 (17-24d)	<40000 (10-16d)	<40000 (8-10d)	—	—
Latent period	—	20-30d	15-25d	8-17d	6-8d	0-2d	0
Time of recovery	3-6w	6-10w	6-12m	5-15m	15-24m	—	—
Prognosis	excellent	excellent	guarded	guarded	poor	poor	poor

3.2.3 HAEMATOLOGICAL DOSIMETRY[29,35]

Changes in the peripheral blood cell counts are one of the most reliable indicators of absorbed dose. The depletion of lymphocytes occurs rapidly following exposure and the cell count reaches the nadir between the second and third day following exposure; most of the decrease occurs during the first 24 hours. The kinetics of lymphocyte depletion and the absolute lymphocyte counts at the end of 48 hours serve as a reliable indicator of dose and prognosis. The granulocytes show an early rise during the first 48 hours and then fall to a lower level by the 10th day. Thereafter an abortive rise occurs between the 10th and 15th day. This is followed by a steady fall in granulocytes, reaching a nadir around the 30th day. In the dose range of 2-5 Gy, granulocytopenia has been shown to be a reliable indicator of dose. The kinetics of depletion of neutrophil counts can be correlated with the dose during the second depletion maximum of granulocyte counts. For absorbed dose of 6 Gy, the second depletion maximum occurs around the 12th - 14th day and for 2 Gy, around the 30th day.

Thrombocytopenia also follows a time course similar to granulocytes without the phase of abortive rise. A fall below 3-5 x 10^4 counts/mm^3 is associated with bleeding. The fall in erythrocyte counts occurs very slowly and cannot serve as a biological indicator of dose. Further details of the variation of different blood cell counts with time after exposure are shown in Figs. 3.2.1 and 3.2.2.

In addition to the cell count depletion mentioned above, there are several other haematological indicators of biological damage which may have some dosimetric and prognostic value:

(a) Decrease in the uptake of tritiated thymidine in PHA stimulated lymphocytes in the dose range 1-8 Gy.

(b) Various immunological changes such as surface markers, mitogen and antigen responses and cytotoxic functions, which may persist for a period of 10 years, have a potential to serve as biological indicators of radiation dose.

(c) Severe monocytopenia immediately after irradiation suggests the exposure of a large portion of the bone marrow. The absence of monocytopenia or a less severe monocytopenia suggests a partial body exposure. Similarly, a rapid fall in reticulocyte counts signals early fatality.

(d) Doses higher than 1 Gy result in a reduction in mitotic index of the cells in the bone marrow. The recovery of the mitotic index occurs in about 8 days. Whole-body exposure in the range of 2-4 Gy has been found to result in complete absence of mitotic activity in the bone marrow.

(e) Following exposure, the mobilisation of granulocytes from bone marrow to the blood stream by injecting ethiocholanolon serves as an indicator of the activity of medullary production of granulocytes.

(f) Bone marrow scans for erythropoiesis as well as cultures of mixed cell colonies and granulocyte/macrophage colonies can serve as a useful indicator of bone marrow dose (and survivors of precursor cells in bone marrow).

(g) In addition to the above, changes in lymphocytes such as nuclear abnormalities and electrophoretic mobility, serum glycoprötein, presence of immature granulocytes and erythroblasts do suggest radiation exposure. However, these changes are not useful for biological dosimetry.

3.2.4 CYTOGENETIC DOSIMETRY[36,37]

General

Cytogenetic dosimetry, based on the analysis of chromosome aberrations in peripheral blood lymphocytes, constitutes a very reliable biological indicator of absorbed dose. Evaluation of the dose is done by the help of appropriate calibration curves and the knowledge of exposure conditions. Larger doses of the order of 1 Gy acute exposure can be evaluated with reasonable accuracy whereas lower doses involve considerable uncertainties. Information regarding the radiation dose can be obtained within 3-4 days of exposure.

Structure of Chromosomes

Chromosomes carry the genetic information in the cells. They are nucleoproteins built from deoxyribonucleic acid (DNA) and the basic proteins called histones. The chromosomes are not visible in non-dividing (resting) cell population. However, when dividing cells enter into mitotic phase, condensation brought out by folding or supercoiling increases the thickness of the chromosomes to 1 μm and renders them visible. Metaphase chromosomes which are clearly visible under the microscope appear as two chromatids attached to each other at the centromere.

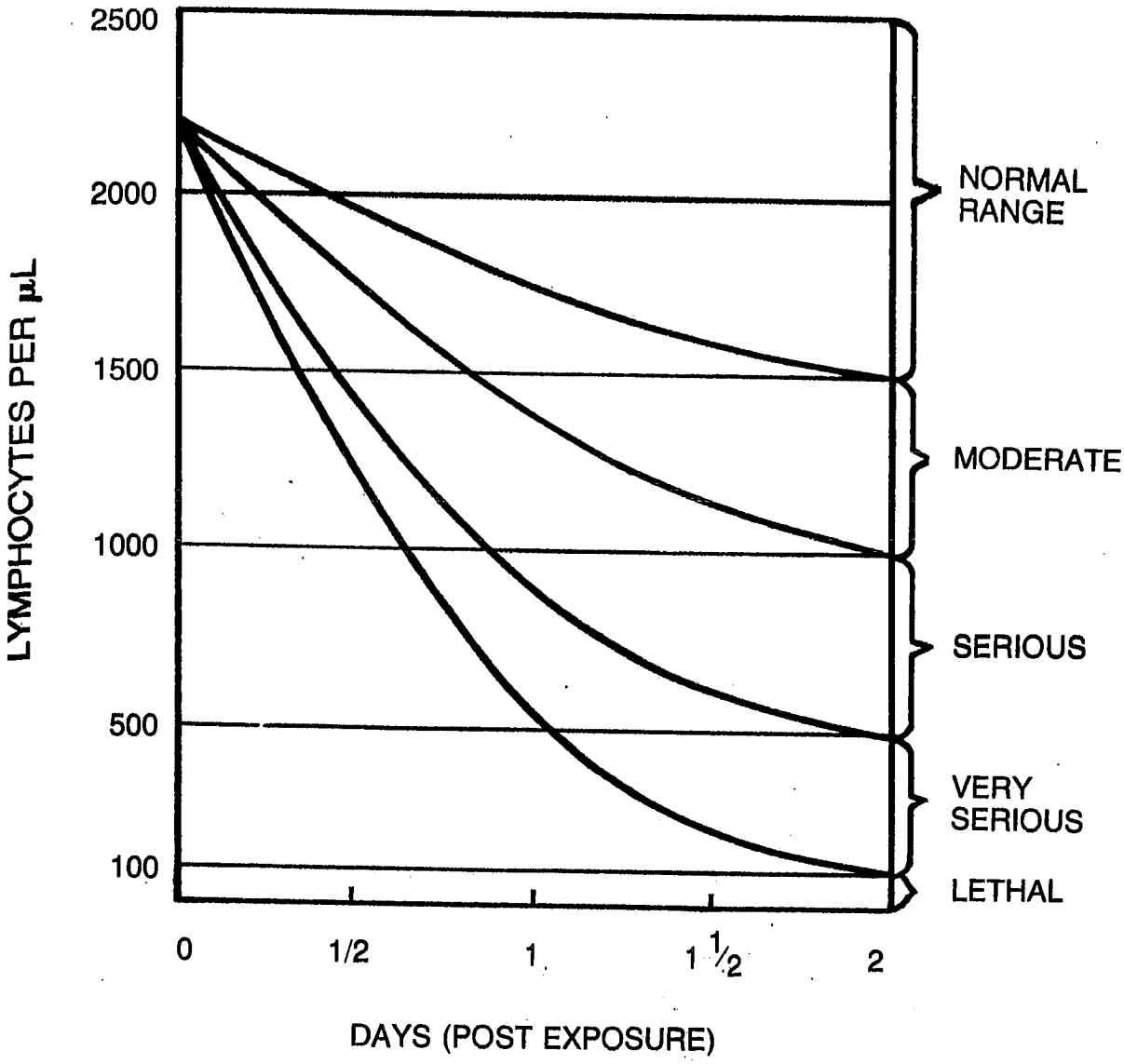

Fig. 3.2.1 PATTERNS OF EARLY LYMPHOCYTE RESPONSE IN RELATION TO WHOLE BODY RADIATION EXPOSURE

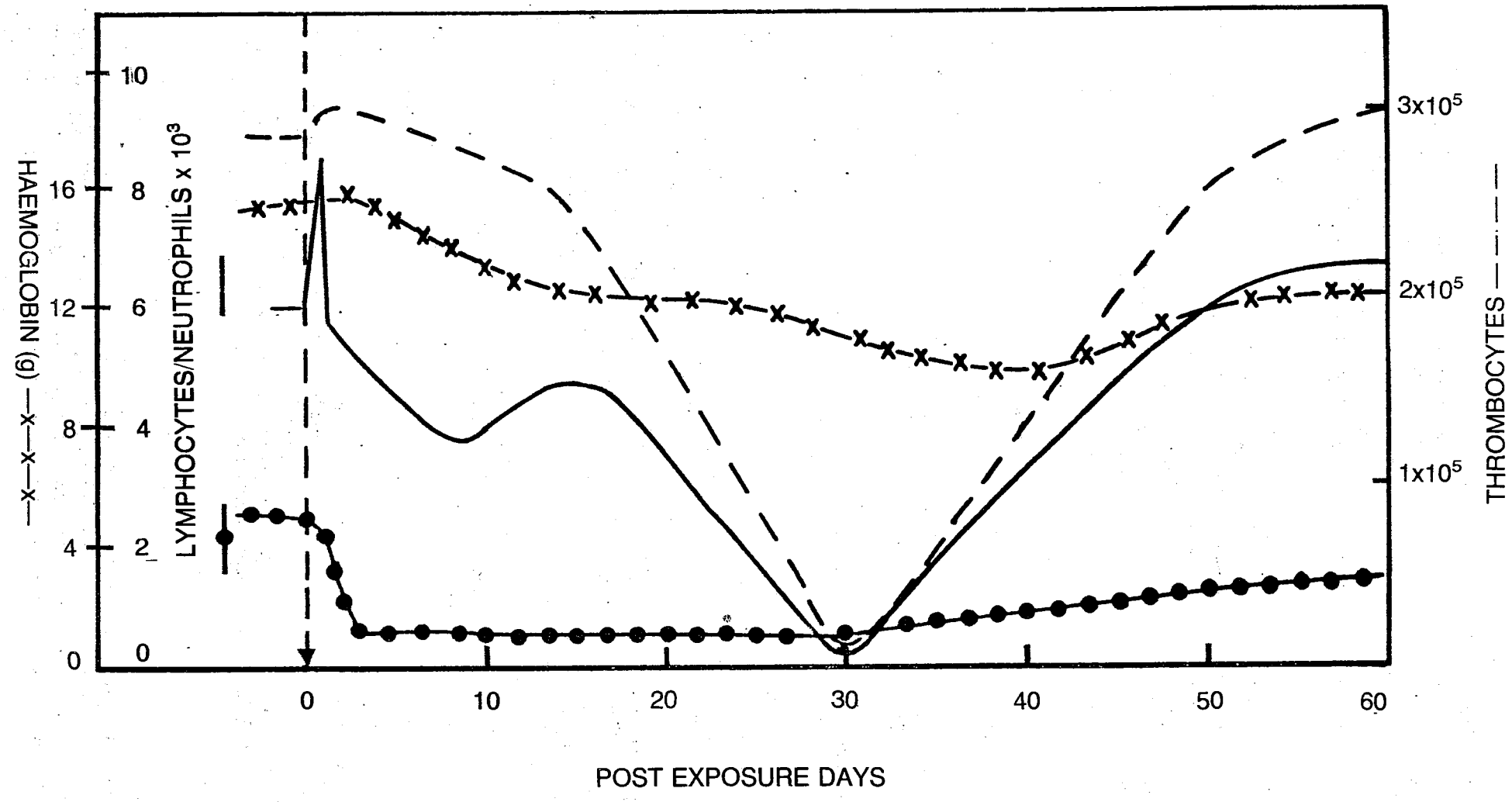

Fig. 3.2.2 KINETICS OF VARIATION OF BLOOD CELL ELEMENTS IN SEVERE HAEMATOPOIETIC SYNDROME

Types of aberrations: Classification

Chromosome aberrations can be induced by DNA damaging agents like radiations and chemicals. When the exposure to radiation occurs in either G_1 or early S phase, chromosome-type aberrations involving both the chromatids occur; on the other hand exposure during late S or G_2 phase results largely in chromatid type aberrations. Lesions on chromosomes can lead directly to simple deletions which can occur very frequently. Lesions on the same chromosomes or two independent chromosomes can interact resulting in intrachange or interchange respectively (Cf. Fig. 3.2.3).

Radiation induced single strand breaks (SSB), double strand breaks (DSB) and base damage appear to be the important kinds of DNA damage leading to chromosome aberrations. Dicentrics, rings and deletions (Fig. 3.2.3) can be clearly identified in the metaphase under the microscope. Symmetric aberrations like translocations and inversions can be detected by chromosome banding technique. Many of the asymmetric aberrations disappear after a few cell divisions as a result of the mechanical difficulties created by these aberrations during mitosis. Symmetrical aberrations are stable and can be transmitted indefinitely. Hence, it is important that chromosome aberrations should be scored during the first post-irradiation metaphase. In lymphocytes this corresponds to 48 hours of culturing.

Peripheral lymphocytes have a diameter of around 6μm. The average lymphocyte count in an adult is around 2500 mm^{-3} (1000-4800 mm^{-3}). T-lymphocytes constitute approximately 70-80% and the rest are B-type. About 80% of the total lymphocytes belong to the redistribution pool and pass through spleen, lymph nodes, lymphatic tissue, tonsils etc. At any time only 2 % of the total lymphocytes (10^{10} cells) are in circulation and the redistribution (recirculation) time is approximately 12 hours. Hence, lymphocytes in any pool (in any part of the body) will be seen in peripheral blood within a few hours. Lymphocytes have variable life span. Approximately 90% of the lymphocytes have an average half life of 3 years; rest of the cells have half - lives in the range of 1-10 days. A very small fraction of the lymphocytes may last for several decades.

Method

Collection of Blood Sample

In the case of partial body exposures a blood sample of 10 ml should be collected after 24 hours of the exposure. This time gap helps the equilibrium to be attained between the circulating lymphocytes with those in different pools. Samples should be collected ideally within 2-4 weeks of exposure to reduce the uncertainty in dose estimation. In the case of serious accidents involving exposure to several Gy, blood samples should be collected before the commencement of blood transfusion or any other treatment. In such situation it is also necessary to take samples at frequent intervals to monitor the changes in blood counts. Sterile glass or plastic containers containing appropriate amount of anticoagulant lithium heparin are ideal for sample collection. The samples can be preserved under cold condition for 2-3 days before culturing, thus enabling the transport of samples to the laboratory from distant places.

Culturing

Blood samples are cultured in a suitable medium (F-10, RPMI-1640, TC-199 or MEM), supplemented with inactivated serum (newborn, foetal calf or human AB serum). Blood is mixed with 0.1 - 0.15 ml of phytohaemagglutinin (PHA) and then transferred into the vials containing the culture medium. Antibiotics such as penicillin (100 IU/ml) and streptomycin (100 μg/ml) are used to avoid contamination. After 45 hours of culturing at 37°C ± 0.5°C, 0.1 ml of colchicine or colcemide solution (25 μg/ml) is added to arrest the cells at metaphase. After a further incubation for 3 hours, the cells are suspended in hypotonic solution (0.075 M KCl) for 10 - 20 minutes at 37°C. After removal of the hypotonic solution, the cells are suspended in 3:1 methanol acetic acid for fixation. The cells are spread on the slides and stained by orcein or Giemsa staining. The details of lymphocyte culturing are shown in Fig 3.2.4. Slides are scanned for metaphases with a microscope at a magnification of x 100, and scoring of metaphase cells is done at x 1000.

Calibration Curve

Every laboratory should generate its own calibration curves for different types of radiations such as beta-rays, X- or gamma-rays, and neutrons. The calibration curve should have atleast 10 dose points in the dose range desired (25-100 cGy or 25-500 cGy). It is ideal to score 100 dicentrics per dose point. Since it is very difficult to do so for lower doses, an attempt should be made to score a few thousand metaphases for each dose point. Calibration curves for

different radiations under different exposure conditions are shown in Fig.3.2.5. For low LET radiations the dose response curve can be described by linear quadratic relationship.

$$Y = 0.0005 + \alpha D + \beta D^2$$

where Y= the number of dicentrics per cell, 0.0005 = the spontaneous background frequency of dicentrics, $\alpha = 1.64 \times 10^{-4}$, $\beta = 4.92 \times 10^{-6}$ and D = dose in cGy.

For neutrons a linear response is obtained:

$$Y = 0.0005 + \alpha' D$$

where $\alpha' = 8.32 \times 10^{-3}$.

Partial Body or Non-Uniform Exposure

When the exposure is restricted to a part of the body, the dicentrics observed arise from the irradiated part of the body. Cells which contain no damage are from (i) unexposed part of the body and (ii) undamaged irradiated cells (e^{-y} of Poisson series). With the knowledge of the distribution of dicentrics among damaged cells, it is possible to arrive at the mean yield Y as follows:

Total number of cells scored (N)	=	1000
Total number of cells containing dicentrics, rings and deletions (N_u)	=	99
Number of cells containing acentric fragments	=	60
Total number of dicentrics (X)	=	86
Number of cells free of dicentrics (N_o)	=	932

(Number of cells with 1,2,3,4 and 5 dicentrics per cell are 56, 9, 1,1 and 1 respectively)

The estimate for mean yield of dicentrics, Y can be derived from the following relationship:

$$\frac{Y}{[1-\exp(-Y)]} = \frac{X}{N - N_o}$$

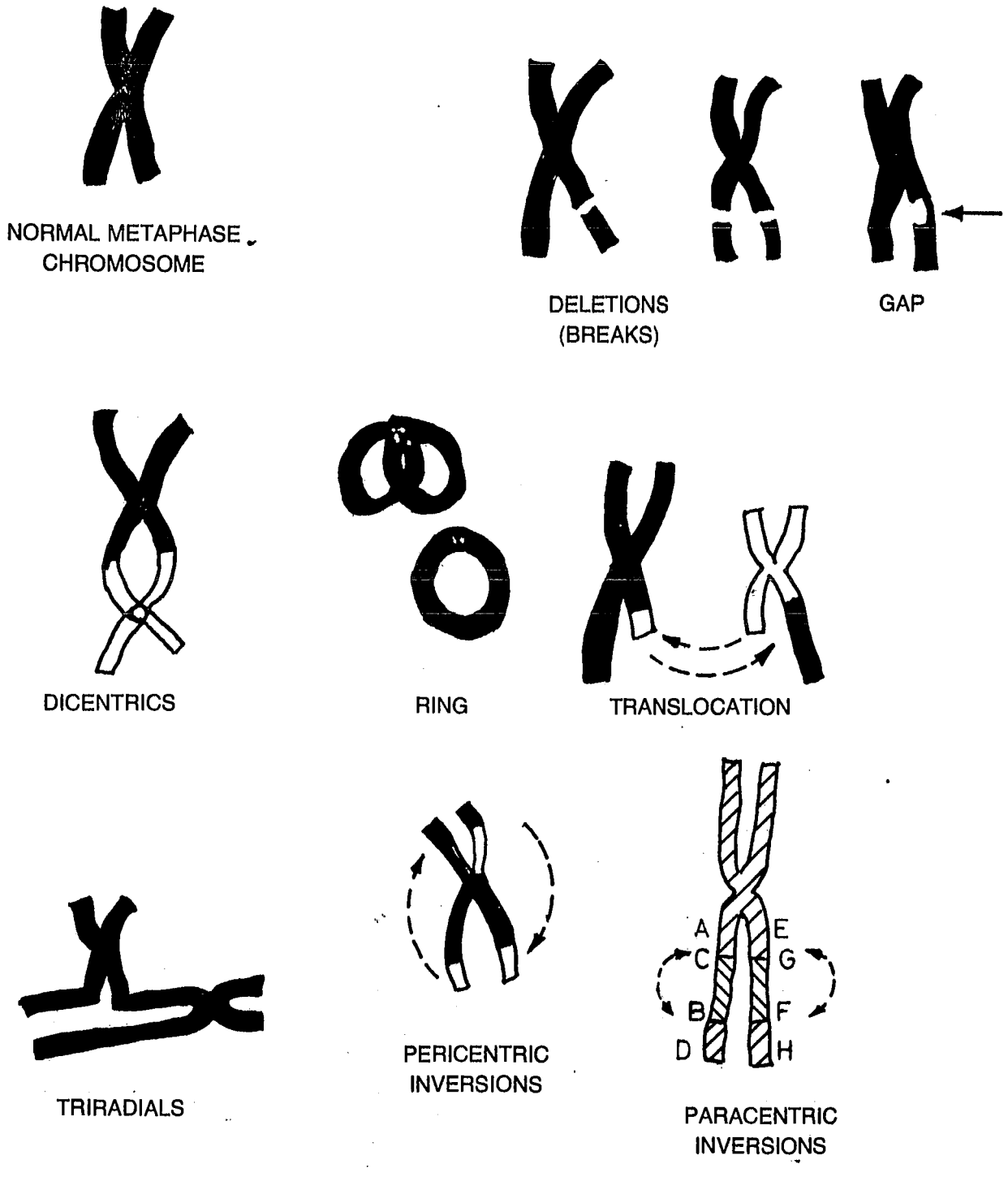

Fig. 3.2.3. TYPES OF CHROMOSOME ABERRATIONS

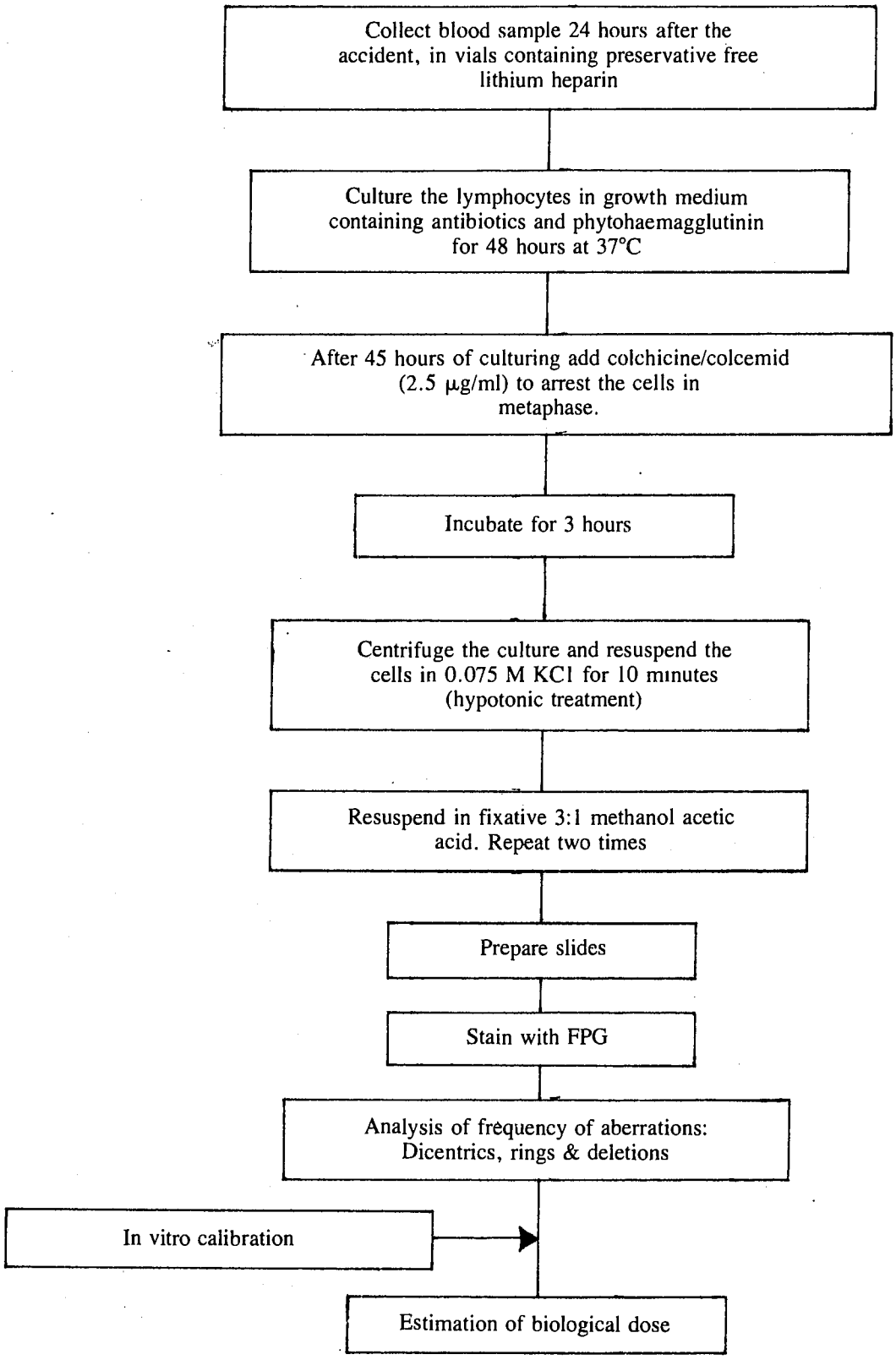

Fig. 3.2.4: CHROMOSOME ABERRATION ANALYSIS

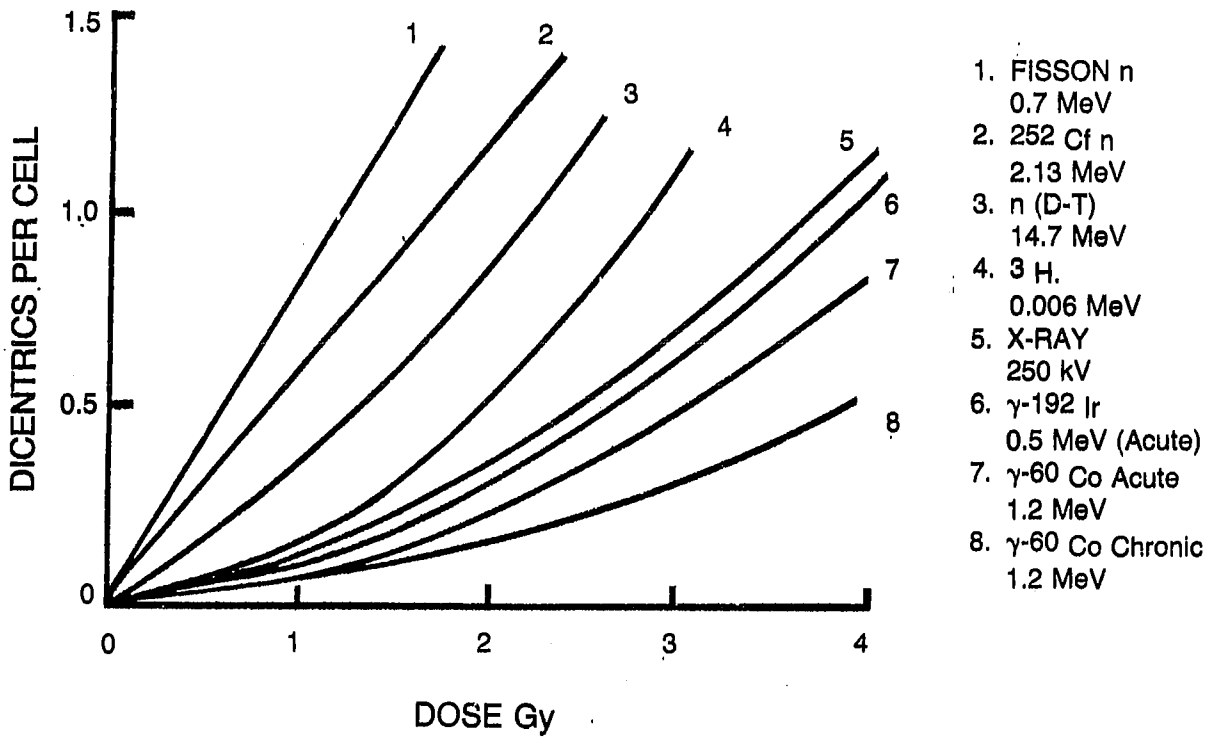

Fig. 3.2.5 INDUCTION OF DICENTRIC CHROMOSOMES IN HUMAN LYMPHOCYTES IRRADIATED IN VITRO (UNSCEAR 1988)

From the value of the mean yield Y, the dose can be read out from the calibration curve.

Alternatively, with the knowledge of the dose response curves for both (i) dicentrics + rings and (ii) acentrics.

$$Y_{\text{dicentrics + rings}} = \alpha_1 D + \beta_1 D^2$$

$$Y_{\text{acentrics}} = \alpha_2 D + \beta_2 D^2$$

the dose D can be estimated by:

$$\frac{X}{N_u} = \frac{Y_{d+r}}{1 - \exp-[(\alpha_1 + \alpha_2) D + (\beta_1 + \beta_2) D^2]}$$

The mean yield Y can be used to calculate the fraction (f) of the cells exposed by the following equation.

$$Y.f = X/N = \frac{\text{No. of dicentrics}}{\text{No. of cells scored}}$$

With the knowledge of dose 'D', the fraction 'p' of cells which reach metaphase can be estimated using the survival response curve for lymphocytes (D ~ 270 cGy). The fraction of the body (F) exposed is related to f and p by the following relationship:

$$F = \frac{(f/p)}{1 - f + (f/p)}$$

Protracted and Fractionated Exposure

Low LET radiation exposure, when protracted over a period of several hours or fractionated, may produce a lower yield of chromosome aberrations, thus resulting in an under-estimation of dose. This is a consequence of repair of radiation damage under low dose-rate exposure conditions, decreasing the contribution of ß component of response. Decrease in the frequency of aberrations follows an exponential function with a mean time of two hours. Lea and Catchside have suggested a modified response equation:

$$Y = \alpha D + \beta G(x) D^2$$

where $$G(x) = \frac{2}{x^2} (x - 1 + e^{-x})$$

where $X=t/t_o$ is the ratio of the total duration of exposure(t) to the mean time of repair (t_o = 2 hours).

Correction for Delayed Sampling

Experience suggests that the frequency of dicentrics remains constant during the first 4-5 weeks after exposure. This is followed by a second phase where the yield of dicentrics falls rapidly to half the value during the next 10-15 weeks. For periods beyond a year, the decrease is exponential with a half life of approximately 3 years (corresponding to $T_{1/2}$ of lymphocytes). Since the decrease in the yield of dicentrics is not consistent in different cases, exact guidelines cannot be provided for correcting the data. In one of the cases multiplying the dicentric yield by 2 for 100 days' delay and 3 for 200 days' delay, has yielded results consistent with physical dosimetry. After a lapse of several years, it is possible to score stable aberrations like inversions and translocations by G-banding. Ankylosing spondilitis and atomic bomb survivors have been investigated by this technique.

Internal Contamination Dose

Meaningful estimation of dose cannot be done by chromosome aberration analysis in the case of most radionuclides due to non-uniformity and many confounding factors. However, exposure to tritium can be assessed with reliability using the standard curve obtained for 250 kV X-rays ($Y = C + 5 \times 10^{-4} D$).

Uncertainty in Dose Estimation

Uncertainties arise from two sources: (i) The Poisson distribution in the yield of aberrations, and (ii) The uncertainty of calibration curve. The standard error due to the yield of dicentrics on the basis of 'a' dicentrics among 'b' cells scored is $a^{1/2}/b$). If the standard error from the calibration curve be 'C', then the total standard error is:

$$S.E. = \pm [C^2 + (a^{1/2}/b)^2]^{1/2}$$

If the yield of dicentrics is X,the doses corresponding to X+1.96xS.E. and X-1.96xS.E., provide the 95% confidence limits for the estimate. Table 3.2.2 shown below provides the 95% confidence limits associated with the estimates.

TABLE 3.2.2 :VARIATION OF 95% CONFIDENCE LIMITS WITH DOSE AND THE NUMBER OF METAPHASES SCORED

Dose estimate (cGy)	Confidence Limits		
	Number of cells scored		
	200	500	1000
10	-	34 - < 0.5	25 - <0.5
25	61 - 3	50 - 10	40 - 12
50	87 - 19	71 - 30	64 - 36
100	135 - 69	121 - 81	113 - 85

Criticality Accidents

In criticality accidents, persons are exposed to mixed neutrons and gamma-rays. The calibration curves for both neutrons and gamma-rays are used. For example,

$$Y_{neutrons} = 0.0005 + 8.32 \times 10^{-3} D_n$$

$$Y_{gamma} = 0.0005 + 1.64 \times 10^{-4} D_g + 4.92 \times 10^{-6} D_g^2$$

where D_n is the neutron dose and D_g is the gamma-ray dose, both doses in cGy.

Following steps are involved in estimation of neutron and gamma doses:

1. Assume that the entire yield of dicentrics is due to neutrons and calculate D_n by using the calibration curve for neutrons.

2. With the knowledge of n:g (from physical measurements) calculate the gamma-ray dose.

3. Calculate the yield of dicentrics expected for this dose by using the gamma-ray calibration curve.

4. Subtract the result from step (3) from the total yield of dicentrics to obtain the neutron contribution.

5. From the result of step (4), calculate the neutron dose.

6. Repeat these steps until consistent estimates of doses are arrived at.

Application in Goiania Accident [26]

Chromosome aberrations analysis was performed in 110 people who were suspected to be exposed to doses higher than 0.1 Gy in the Goiania accident in Brazil. The dosimetry was based on the frequency of dicentric rings and acentric fragments, using a standard curve available for ^{137}Cs gamma-rays at a dose-rate of 0.12 Gy/minute. For the highly exposed persons the dosimetry was based on the counts of 100 metaphases whereas for those exposed to lower doses, 200-300 metaphases were scored. The estimated doses were in excess of 1 Gy for 21 people; 4 Gy for 8 people. The maximum exposure was 7 Gy. People with non-uniform exposure, as confirmed by severe localised damage (with whole

body doses of 0.5 Gy, 0.6 Gy, 0.7 Gy, 1.3 Gy, 2.7 Gy and 4.5 Gy) showed deviation from Poisson distribution of dicentric chromosomes in lymphocytes. Even though many other individuals were suspected to have undergone non-uniform exposure, the distribution of dicentrics was consistent with Poisson distribution. Among the four casualties which occurred within four weeks of admission to the hospital, cytogenetic dosimetry yielded doses in the range 4.5 - 6 Gy. This is consistent with the present estimates of $LD_{50/60}$ values for human beings. These observations confirm the reliability of chromosome aberrations analysis in accidental exposures.

Scoring of Micronuclei in Cytokinesis Blocked Lymphocytes[38-40]

Chromosome breaks frequently lead to acentric fragments which tend to remain in the cytoplasm and subsequently appear as micronuclei. Scoring of micronuclei in cultured lymphocytes is done by blocking the cytokinesis using cytochalasin B. The micronuclei are scored in binucleated lymphocytes. By this method a dose as low as 2 cGy can be detected in vitro by scoring 9000 binucleated cells. Fig. 3.2.6 shows the dose-response curves in the range 0-4 Gy, based on the results reported by Kormos & Koteles (1988), using 200 kV x-rays (1 mm Cu filter) at a dose-rate of 0.287 Gy. min^{-1} and Sreedevi Balakrishnan and Bharati Bhatt (1989), using cobalt-60 gamma-rays at a dose-rate of 0.5 Gy. min^{-1}. These data suggest a linear-quadratic relationship in this dose range. The method is sensitive enough to detect an exposure of 0.25 Gy in vivo. Even though this method may be less specific and less sensitive compared to chromosome aberration analysis, simplicity, ease and speed of scoring and the possibility of automatic analysis with pattern recognition devices can render this technique to be extremely useful as a biological dosimeter in accidents involving a large number of individuals. An additional advantage of this technique is that the scoring of the micronuclei does not need highly specialized technicians as in the case of chromosome aberrations analysis; several thousand micronucleated cells can be scored in a person-day as compared to about 100 metaphases in the case of chromosome aberrations analysis. However, many parameters such as dose-rate effect, kinetics of decay and many other aspects of this technique need to be perfected and standardised to achieve higher reliability.

3.2.5 BIOCHEMICAL INDICATORS OF DOSE[41]

Analysis of biochemical parameters in blood and urine may serve as useful indicators of dose. None of the biochemical parameters such as hyperglycaemia followed by hypoglycaemia (0.5 g/L) by 3rd day and inhibition of ^{125}IUdR uptake following exposure can serve as reliable dosimeters. Increase in salivary amylase following exposure to doses higher than 0.6 Gy, to a maximum by the first day and returning to normal by 3rd day would suggest exposure of the salivary glands.

Urinary excretion of 17-ketosteroids, various amino acids and variation in the creatine/creatinine ratio are useful indicators of exposure during the first few days and their levels return to normal by the end of the first week. Excretion of amino acids such as taurine, ß amino isobutyric acid (BAIBA), glutamic acid, aspartic acid, histidine, lysine and glycine increases upon irradiation. Following whole body exposure, 3-5 times increase in the excretion of BAIBA has been reported. The experience with other nucleic acid metabolite, deoxycytidine (DOC), is too limited to consider it as a useful indicator of dose.

Creatine excretion is an indicator of muscle damage as a result of exposure to radiation. The inability to metabolise creatine results in an increase in the creatine/creatinine ratio in urine. Even though creatinurea cannot be exactly correlated with dose, it is a sure indication of whole body exposure. In accidents involving whole-body irradiation the creatine/creatinine ratio showed an increase whereas partial body exposures did not result in any significant change in this ratio.

3.2.6 OTHER DOSIMETRY METHODS

Neutron Activation Analysis [42]

Neutron activation resulting in the formation of ^{24}Na and ^{32}P can serve as a useful indicator of dose in the case of persons exposed to neutron fields in accidents. The activity can be measured in biological samples such as blood, urine, hair, finger nails or in extraneous objects such as clothing, coins, jewellery, wristwatch and other metallic objects carried by the individual.

Electron Spin Resonance (ESR) Studies [43, 44]

ESR studies on biological samples such as bone, teeth, hair and skin, following irradiation can detect doses as low as 0.3 Gy. The intensity of the ESR signal is proportional to the dose and can be used to detect lethal as well as sub-lethal doses. The intensity of the ESR signal is greater for photons of lower energy and very poor for neutrons. Since the signal persists very long, it can be a useful method for accidents in which the dosimetry is done after a long period.

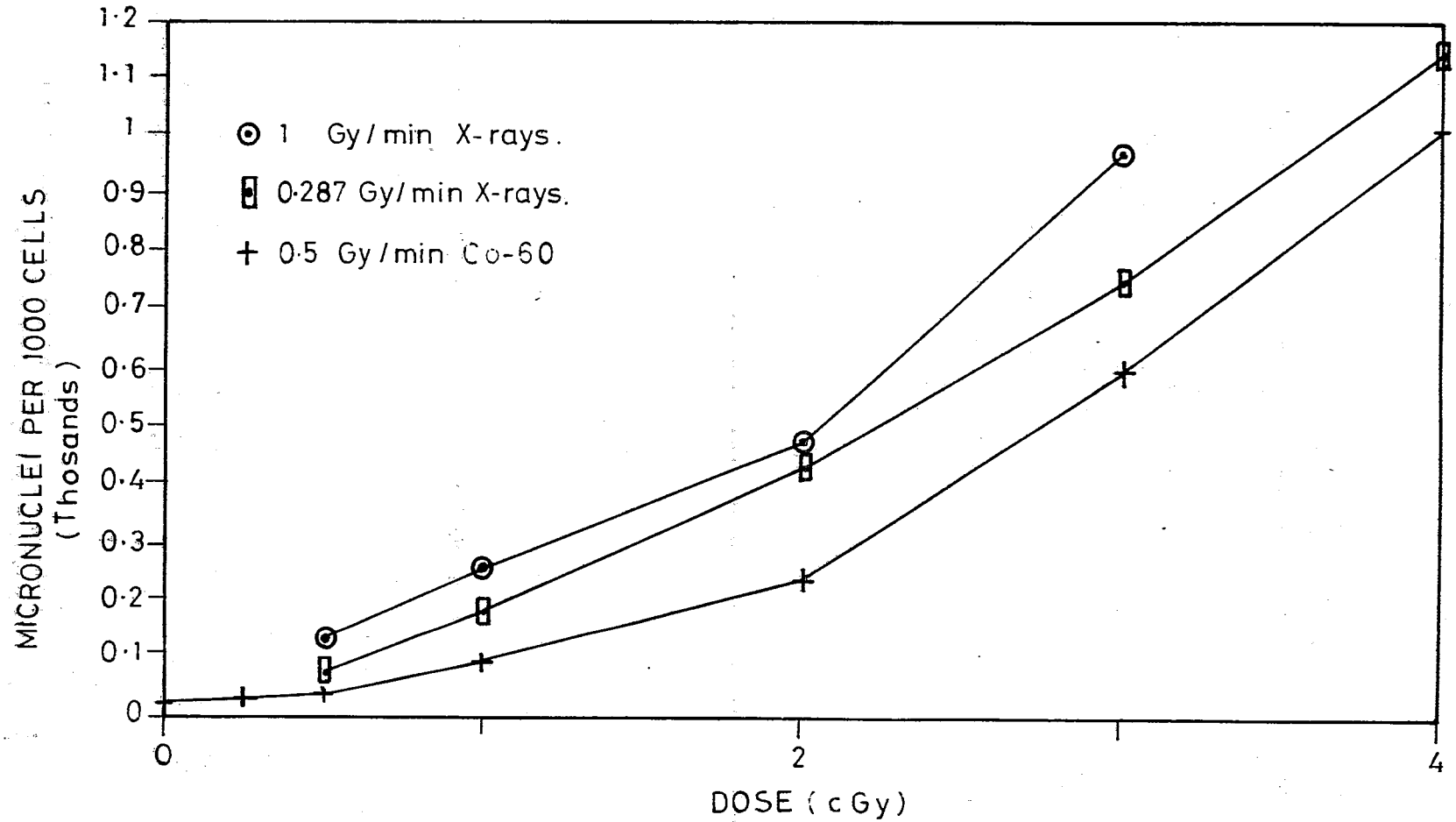

Fig. 3.2.6. DOSE RESPONSE CURVES FOR RADIATION INDUCTION OF MICRONUCLEI

Cell Death in Hair Follicles[45]

Cell death in hair follicles is dose dependent in the range 0.1 - 1 Gy. The decrease in hair width resulting from the death of hair follicles can be correlated with dose in the range 1-10 Gy. This method is yet to be developed as a biological dosimeter.

Sperm Analysis [46]

Sperm analysis provides a biological dosimetry technique, thanks to the sensitivity of certain stages of spermatogenesis (spermatogonia B). Exposure to low doses (1 Gy) can result in the drastic reduction in sperm counts by around 60 days after exposure to radiation. A rapid fall in sperm counts can occur between the 40th and 60th day post-exposure. It is important that the first sperm sample should be collected within 40 days after exposure and the second after the 60th day of exposure. An important limitation of this technique is that the information on the dose can be obtained only after 2 months. Fractionated or protracted exposures result in as much depression in sperm counts as acute exposure. Sperm analysis can serve as a very useful prognostic indicator of the functional impairment of the reproductive system. Generally, doses of 0.5 Gy lead to oligospermia which results in temporary sterility. Severe oligospermia (1.0 Gy) or azoospermia (>2Gy) leads to a prolonged sterility.

Neurophysiological Dosimetry[47]

Irradiation causes changes in many chemical mediators associated with central nervous system function. These include acetylcholine - cholinesterase balance, aspartic acid, adrenergic amines, gamma aminobutyric acid, membrane permeability and acid-base balance. These could result in changes in the cerebral electrical activity. These changes appear immediately after irradiation. Modification of the electrical activity of the brain is reflected as changes in the electroencephalograph (EEG). The response can be observed for doses above 0.25 Gy. It is an excellent dosimetry tool in situations where it is not possible to resort to cytogenetic methods because of blood transfusion or when the dosimetry is done long after the exposure.

SECTION 3

Physical Dosimetry : External Radiation

3.3.1 INTRODUCTION

All radiation workers (unless otherwise exempted because of low dose-rates or because of the low penetration of radiations to which they are exposed in the work place) wear a personnel monitoring dosimeter while working in controlled areas. Such dosimeters can help to evaluate the dose equivalents received by a person in a radiation accident. Criticality accident dosimeters can also be used to rapidly screen exposed persons.

Where doses in the body in general and in the bone marrow in particular can be determined with sufficient precision, it is possible to make a relatively accurate prognosis. The intensive treatment which is given to exposed individuals may completely change the prognosis. Dosimetry is most valuable in the case of very high doses because whatever the possible error, one can be reasonably sure whether the doses are in the non-lethal (0.5-1 Gy) or lethal range (> 6 Gy).

A personnel monitoring dosimeter must estimate with reasonable accuracy the dose equivalent received by the workers from different radiations of different energies and at different dose -rates. It must be small, rugged and cheap. The choice of dosimeter(s) will depend on the types of radiations and the dose equivalent levels to be monitored.

3.3.2 TYPES OF DOSIMETERS

The different types of personnel monitoring dosimeters which could be of use to estimate dose equivalents for the purpose of medical management of radiation accidents include :

1. Film dosimeter,[48]
2. Thermoluminescent dosimeter,[49]
3. Criticality badges,[50]
4. Glass dosimeter,[51]
5. Chemical dosimeter.[52]

The personnel dosimeters, most commonly used in India, are shown in Photographs 10(a) to 10(d) in plate-III.

3.3.3 LOCATION OF DOSIMETER

If only one dosimeter is used, it is worn on the body in a position where it is representative of the most highly exposed part of the trunk, i.e. at the chest level.

3.3.4 COMPARISON OF DIFFERENT DOSIMETERS

Photographic film is useful for monitoring in medical centres and industrial radiography installations. This dosimeter provides a permanent record and may give information regarding work habits. The pattern on the film may also help in the case of high doses recorded to determine genuineness of the dose. In controlled areas where a health physicist assists in evaluating radiation doses, thermoluminescent and glass dosimeters provide the best choice on the basis of their better precision of dose measurements.

Chemical dosimeter is relatively insensitive and therefore not useful in evaluating low doses, but may be used for evaluating high doses in accidents.

A special dosimeter, or special components in a general purpose dosimeter, may be necessary to meet specific requirements, for example, criticality accident dosimeters.

A comparison of the different personnel monitoring dosimeters is given in Table 3.3.1.

3.3.5 X-, GAMMA, BETA AND THERMAL NEUTRONS

(a) Film Badges

X-rays, gamma rays, beta particles and thermal neutron doses can be evaluated using a film similar to photographic/X-ray film, mounted in an appropriate holder [see photograph 10(a) in plate-III] . Such a holder will have a number of metallic filters, open window and a plastic filter. The blackenings in the film under the different regions help to discriminate the nature of radiation, determine the energy in case of X-rays and evaluate the doses. A cadmium filter helps in the evaluation of the thermal neutron doses.

(b) TL Dosimeters

The thermoluminescent phosphors used for personnel dosimetry include lithium fluoride, lithium borate and calcium sulphate. The phosphor in the form of powder or discs is kept in a multifilter dosimeter badge. [see photograph 10(b) in plate - III] This arrangement helps to discriminate the nature and energy of radiations and evaluate the doses. Commercially available LiF-600 and LiF-700 are used in the evaluation of thermal neutron doses.

3.3.6 FAST NEUTRON MONITORING

(a) Film Dosimeter

Normally special films (e.g. Kodak NTA) are used to record recoil proton tracks for fast neutron monitoring[53]. [see photograph 10(c) in plate-III] . The application of such a dosimeter is some what limited because of its high neutron energy threshold and the response dependence on neutron energy.

(b) Albedo dosimeter[54]

Albedo dosimeter is primarily based on the principle that high energy neutrons leave the body as thermal and intermediate neutrons after having been scattered in the body. They are detected at the surface of the body by means of a detector for thermal neutrons. They have limitation of severe energy dependent response.

3.3.7 DOSIMETRY IN RADIATION ACCIDENTS

For radiation accidents such as those in industry and medicine, dosimetric methods used routinely for personnel monitoring are usually adequate for preliminary assessment of dose.

Nuclear accident dosimetry generally refers to criticality accident dosimetry and provides, in cases of accidents, quick evaluation of doses for appropriate medical management. Such a dosimetry system is generally based on a combination of personnel and area monitors and measurements of induced activity in the exposed persons.

Criticality Dosimeter

Criticality dosimeter badge for neutron and gamma monitoring is used by personnel working in nuclear fuel processing plants, fuel storage facilities, critical assemblies and other areas in a nuclear reactor where there is a possibility of exposure in case of accidental or uncontrolled criticality. The detector foils used include gold, copper, indium and sulphur to evaluate doses at various neutron energy intervals. Calcium sulphate embedded teflon disc in a tin box is used for gamma dose measurement [see photograph 10 (d) in plate-III]. The neutron dose can be estimated within an accuracy of $\pm$ 50% within 24 hours if the dose is greater than 25 cGy (rad), and of $\pm$ 25% within one week. Accuracy of gamma dose estimation is $\pm$ 20%. The lower limit of detection is 10 cGy (rad).

Reconstruction of Dosimetry in Radiation Accidents

Doses to irradiated organs have to be estimated with accuracy and minimal delay to facilitate the medical management including (i) initial screening , (ii) selection of individuals who would benefit from medical treatment and (iii) guidance in the choice of treatment methods.

(a) Screening

This refers to the collection of any information or samples for dose estimation that permits segregation of personnel into irradiation groups at different dose levels. This includes :

(i). Collection and evaluation of personnel dosimeters;

(ii). Collection of all information concerning the dosimeters, such as location of dosimeters on the individuals and the locations of the individuals in the facility at the time of the accident, duration of irradiation etc.

In case the dosimeter contains foils such as indium (for a quick indication of neutron exposures), appropriate readings are taken with a GM probe.[55]

Further, supplementary information is obtained by:

(i). Measurements of radiation levels at the place where persons received exposure, wherever feasible;

(ii). Discussion with the persons involved to establish the duration of the exposure. This helps to estimate the doses and segregate the exposed workers with respect to their doses.

(b) Decision

On the basis of the information collected, screened persons must be sent to appropriate treatment facilities with precise instructions. A reference level of 250 mSv (25 rem) of gamma dose (or less for neutron dose) may be used to categorise the irradiated persons.

(c) Reconstruction

Here the rough dose estimated by the earlier screening process must be confirmed. This involves:

(i) Estimation of the field composition. This includes evaluation of quality and energy/spectra of incident radiation;

(ii) Estimation of the irradiation geometry, such as locations of persons and the dosimeters in the radiation field, field dimensions etc.,

(iii) Dose measurements simulating the irradiation conditions: Accurate and properly calibrated dosimeters should be used for this purpose, along with appropriate phantoms [See Photograph 11 in Plate-III] .A phantom is a tissue-equivalent material of the same size as the irradiated person and which will absorb and scatter the radiation to the same extent as the human body. Reconstruction procedures will also help to estimate doses for persons who were not wearing dosimeters at the time of the accident.

(d) Computation of Dose Distribution[56]

In accidents involving exposure to a large number of persons it may not be feasible to measure the doses of every individual immediately. Computer codes can be used for evaluation of energy spectra of the incident radiation and to obtain the quality and spatial distribution of the dose equivalent in the irradiated volume. A few of the computed doses may be verified with actual measurements.

(e) Spatial Distribution of Doses

Another important element in the prognosis is the spatial distribution of dose. In the case of accidents, irradiation is never homogeneous. Therefore, the concept of average dose in the bone marrow, while useful in establishing the dose to an order of magnitude, is insufficient as a basis for prognosis. Relatively small volumes of bone marrow which have escaped exposure or have been only slightly irradiated, according to the geometry of the exposure, are sufficient to repopulate sterilised haemopoietic areas through cell migration so long as the marrow stroma has not been damaged.

TABLE 3.3.1: COMPARISON OF PERSONNEL MONITORING DOSIMETERS

Dosimeter	Film Badge	TLD	Glass dosimeters	Chemical dosimeters	Criticality badges
Material	Photographic film specially made for personnel monitoring use. (e.g. Kodak Type II)	$CaSO_4$:Dy;CaF_2: Dy; LiF as TLD-100, TLD-600 TLD-700; $Li_2B_2O_7$: Mn; Mg_2SO_4: Tb	Silver activated metaphosphate glass/ fluoride glass (Radiophotoluminescence) (spectral absorption) cobalt borosilicate glass.	FBX (typical) 0.20 mM ferrous ammonium sulphate, 50 mM benzoic acid and 0.20 mM Xylenol orange in 0.05 N. aqueous sulphuric acid.	Badge containing activation detector foils (gold, copper, indium) and TLD disk.
Principle	Radiation dose produces film blackening which is proportional to dose.	Thermoluminescent material material when heated releases light proportional to previous radiation dose.	1. Radiophotoluminiscence; exposed glass when stimulated by ultraviolent or near visible light gives luminiscence proportional to the radiation dose. 2. Special absorption changes, proportion to the radiation dose.	Ferrous ions oxidised to ferric ions which form a complex with xylenol orange having maximal absorption at 540 nm.	1. Neutron dose is estimated by activation methods, thermal and intermediate neutrons by cadmium difference metho and fast neutrons by the threshold detector method. 2. Gamma dose is estimated by the TL dosimeter.
Dose range	Fraction of mSv to 100 Sv.	Fraction of mSv to 1000 Sv.	1. Few μ Sv to 10^4 Sv. 2. 10^2 Sv to 10^6 Sv.	1 mSv to 50Sv.	Few mSv to 10 Sv for neutrons, 100 mSv to 100 Sv for gamma rays.
Advantages	1. Permanent dose record. 2. Contamination pattern on film identified. 3. Exposure field/ direction pattern can be seen.	1. Accurate dosimetry, 2. Wide measurable dose range. 3. Stable dose information (no fading). 4. Versatile dosimeter shapes and sizes. 5. Reusable.	1. Longterm integration capability. 2. Wide measurable dose range. 3. Good storage stability. 4. Reusable.	1. Tissue equivalent. 2. Accurate dosimetry.	Accurate dosimetry.
Disadvantages	Dose information is affected by 1) temperature, humidity and chemicals., 2. aging of film.	1. No permanent record of radiation. 2. Exposure pattern cannot be seen.	1. Sensitive to surface defects and surface defects and contamination with dirt, grease etc. 2. Extensive cleaning procedure before every read out.	Solution stable only for two weeks.	1. Interpretation of dose distribution is cumbersome. 2. Should be measured within a few days otherwise activation information will be lost.

SECTION 4

Physical Dosimetry Techniques : Radioactive Contamination

3.4.1 EXTERNAL CONTAMINATION

The initial measurements made after an accident determine possible external or surface contamination. The presence of radioactive contaminants indicates a possibility of internal uptake of these contaminants and also possible spread of the contaminants. These measurements are usually made in terms of gross beta-gamma or alpha emitters, or both, rather than for specific radionuclides.

Alpha Contamination Monitoring

Surveys for alpha contamination are made to assess the level of external contamination that subsequently could be assimilated into the body by inhalation, ingestion or by absorption through wounds, but rarely through intact skin. The low penetrating power of alpha particles imposes a restriction that there should be no absorbing material between the detector and alpha source. The probe window must be very thin--about one mg/cm^2 thickness only. ZnS(Ag) scintillation type probe with a photo-multiplier assembly is generally used for measurement of alpha particles [see Photograph 12(a) in Plate IV]. If there is a pinhole on the probe window there will be a noise due to leakage of light. As an alternative, very thin-walled (0.5-1.0 mg/cm^2) end window GM probes can also be used for measuring alpha contamination provided the associated beta emission is not very high or there is very little beta contamination. The first measurement with the end window probe gives both alpha and beta contamination together. A second measurement with a thin paper introduced between the probe and the surface gives beta contamination only. Subtracting the second measurement from the first gives a measure of alpha contamination.

Difficulties and Precautions in Alpha Monitoring

1. Monitoring for alpha contamination should be done as close to the surface as possible., so that absorption of alpha particles by air is minimum.

2. In this process, extreme care should be exercised to avoid contamination of the probe.

3. If the probe is scintillation type, it should be light tight (without any pinholes).

4. Alpha contamination may be highly localised; hence the probe should be moved over the surface very slowly.

5. The contaminated surface should not have water or accumulated dirt which might absorb the alpha particles resulting in lower estimates.

6. In the absence of specific information, a conversion factor of 4 is recommended for converting counts per minute to disintegrations per minute. However, the efficiency of the alpha detector system should be accurately estimated with a standard source to obtain correct values. ALSCIN probes manufactured by ECIL Hyderabad or PLA Electro Appliances, Bombay are suitable instruments for such measurements.

Beta-Gamma Contamination Monitoring

Beta and gamma radiations are emitted simultaneously by many radionuclides. The techniques and instrumentation employed for their detection are the same. Under most situations, an end-window or side window Geiger Muller (GM) probe [see Photograph 12(b) in Plate-IV] is used for beta gamma contamination measurements. The efficiency of the counting system should be evaluated in advance with the help of a standard beta gamma source. Some GM instruments like "Teletector" are also designed for higher level dose rate measurements. GM instruments can be saturated by high radiation levels so that false readings or even zero readings are possible in the presence of a high radiation field. Photographs12(c) and 12(d) in Plate-IV show two sensitive GM-type radiation field measuring survey meters.

Discrimination between beta and gamma radiations is made by using the window shutter which acts as a shield against beta radiation. The reading with the window closed with the shutter gives the gamma component. The difference between the readings with the window open and window closed gives an estimate of the beta component.

Simple general conversions from cpm to dpm can be made by multiplying the counts by 10, in case the GM counter is not calibrated with a standard source.

Hand Monitors

Alpha and beta-gamma hand monitors are used to measure the level of contamination on hands. The alpha hand monitor has a scintillation ZnS(Ag) detector with a photomultiplier assembly. The detection efficiency is about 25 per cent. The beta-gamma hand monitor has an array of thin walled (30 mg/cm^2) GM tubes with a detection efficiency of about 10 per cent. Both types of hand monitors have audiovisual alarm systems incorporated into them. Following precautions should be taken while checking the hands :

(i) Hands should be washed with soap/mild detergent and dried before checking;

(ii) Metal rings and wrist watches should be removed while checking hands for contamination;

(iii) Periodic cleaning and calibration of the monitors with a standard source are absolutely necessary for its efficient functioning. Beta-gamma hand monitors of type PBM-183-A and alpha hand monitor of type-183-C manufactured by PLA Electro Appliances, Bombay are examples of instruments of this type.

A beta-gamma hand monitor is shown in Photograph 12(e) in Plate-IV. The sketch of a hand and foot monitor is also shown in the same plate [see Photograph12(f)]. An array of GM tubes is present below the position of the feet in the equipment to detect any contamination present on the feet.

Surface Contamination monitor

A contamination monitor with a thin walled (30 mg/cm^2) GM counter is used for checking beta-gamma contamination on clothing. The contamination monitor has audiovisual indications and the level of contamination in counts per second can be read on a countrate meter. The same monitor can be used for measuring alpha contamination on body and clothing by replacing the GM probe with a scintillation type alpha probe (Type PSP 649 No.004 made by PLA Electro Appliances).

Contamination monitor of ECIL model No.4552 or PLA types CM 928 and CM 927-D (for beta gamma and alpha contamination respectively) can be used for contamination monitoring of body and clothing.

Wound Monitors

The degree of difficulty encountered in measuring contamination in wounds depends upon the nature of contamination. Measurement of beta-gamma contamination can be done fairly accurately with the help of a thin walled GM detector connected to a contamination monitor. The problem associated with beta gamma contamination monitoring in wounds is the inability to locate minute radioactive particles inside the wound. A small end-window detector, about 1 cm in diameter, placed over the wound surface works almost like a special wound probe. The window is usually covered with a thin piece of plastic to prevent contamination of the probe. The sensitivity of the end-window detector is very good and its small size is good enough to locate the radioactive particles. Alpha emitting radionuclides are difficult to monitor in wounds. A thin film of moisture from decontamination solutions, blood or any overlying tissues will absorb alpha radiations and effectively shield the source. For example, a plutonium particle deposited in a tiny scratch can easily be missed by an alpha probe unless there is associated surface contramination in the region of the wound. Hence wound probes to detect alpha radiations are not practical. But certain alpha emitters have accompanying penetrating radiations which are easier to detect than alpha radiations. For example, plutonium-239 can be detected by counting the 17 keV, L, X-rays of the uranium daughter. Another technique for detecting alpha emitters depends on counting an associated radionuclide which has emission characteristics more favourable for counting. Plutonium 239, for example, nearly always contains a small percentage of Americium-241 as contaminant. The 60 keV gamma rays emitted by Americium are more penetrating and more easily measured than 17 keV X-rays from Plutonium.

The most practical and least expensive instrument is a small NaI (Tl) scintillation detector (2.5 cm dia. and 1.0 mm thick NaI (Tl) crystal) that does not have to be introduced into the wound. By using collimation to locate the activity first in the horizontal plane and then in a vertical plane, the depth of contamination can be estimated.

The minimum detectable amount with such an instrument is about 0.37 Bq (.01 nCi) on the surface and 3.7 Bq (0.1 nCi) at 1 cm depth. The desirable counting time is about 10 minutes. One of the drawbacks of this counter is the background counting rate which can be reduced by 5 to 10 cm lead shielding. Instruments of this type should be calibrated in advance so that count rate can be properly interpreted in terms of activity deposited in the wound.

3.4.2 INTERNAL CONTAMINATION

Nasal swabs

Nose blow samples or nasal swabs are taken from a contaminated person prior to showering. The sample is collected on a moist, clean, cotton tipped applicator or on moistened filter paper on swab stick. Separate applicators should be used for each nostril and should be taken by a health physicist or nurse in order to avoid cross contamination. Care should be exercised to prevent the nasal swabs getting contaminated from facial contamination. Applicators intended for counting alpha contamination must be dried since a film of water gives enough shielding to prevent reliable detection of alpha contamination.

The presence of contamination in the nose, particularly if the reading is similar from both the nostrils, is a positive indication of inhalation of the contaminant. A low amount or absence of contamination in the nose must not be regarded as evidence of minimal internal contamination. Only the nose blow samples or the nasal swabs, taken immediately after suspected inhalation at the site before showering, can be a useful guide.

A rule of thumb generally used in the case of plutonium inhalation is that a value greater than 500 dpm indicates a possible serious exposure, while results less than 500 dpm indicate a low order exposure. Contamination of a high value in one nostril and a lower value or no contamination in the other nostril indicates contamination by means other than inhalation. Nasal swabs are extremely useful because of their early availability but they should always be followed by more definitive in-vivo measurements.

In vivo Measurements

Bioassay techniques and whole body counting are employed to assess internal contamination.

Bioassay Techniques[57]

Any radioactive material entering the body becomes an internal emitter. It will continue to irradiate the tissues until it is either excreted through urine or stool or it becomes a stable isotope by radioactive decay.

Urine and stool samples are therefore collected from subjects suspected of internal contamination. These samples are subjected to radiochemical analysis and from the excreted amount of activity, the quantity of activity originally deposited inside the body is arrived at using standard equations.

The radiochemical methods for separation of the radionuclides from urine/faeces are described in Ref.58 and 59. The interpretation of results of bioassay monitoring is discussed in detail in Reference 60.

Whole Body Counting

Whole body counters are used to detect beta gamma radiations that are energetic enough to escape from the body. Highly sensitive detectors are employed to detect and measure the internal contamination. [see Photograph 13(a) in Plate-V]. Whole-body counting is usually carried out in a heavily shielded room that provides the necessary low radiation background. Sometimes the high sensitivity of the detection system may become a limiting factor in case of high level internal contamination. The whole body counting system is designed to assess low levels of internal contamination only. The detection system should be used at greater distances or suitable absorbers around the detector should be used in cases of high level accidental exposures. The shadow shield whole body counter [see Photograph 13(b) in Plate-V] is a special light weight transportable counter that incorporates the principles of a room type whole body counter but without the massive shielding associated with it.[60] The shadow shield whole body counter uses a NaI (TI) crystal (10.16 cm x 7.62 cm) as the detector with a total shield weight of only two tonnes. A few thousandth part of the maximum permissible body burden in total body (370 Bq or 10 nCi) for various gamma emitting isotopes could be detected within an error of less than 20 percent for a counting time of one hour.

Whole body counting is not feasible for alpha emitting radionuclides unless they also emit penetrating X-rays or gamma rays. For example, plutonium-239 is an alpha emitter and is of considerable importance in view of its inhalation hazards. Internal contamination due to plutonium-239 cannot be measured by an ordinary whole body counter. Since inhalation is the predominant mode of intake of plutonium, the measurement of plutonium in the lungs is all the more important. The 17 keV X-rays emitted by plutonium is advantageously used for measuring

plutonium lung burdens. The whole body counting set up at the basement of BARC Hospital [see Photographs 13 (a) to 13(h) in Plates - V & VI] has a phoswich detector for in-vivo measurements of plutonium[61]. The phoswich detector assembly consists of a 20 cm dia x 3 mm thick NaI (TI), crystal and a 20 cm dia. x 5 cm thick CsI (TI) crystal. Reduction in background of the primary detector by a factor of 5 (in the 14-25 keV range) has been achieved by employing a modified rise-time to pulse-height converter which operates the secondary detector in anti-coincidence with the primary detector. Plutonium counting in-vivo involves considerable error because of the physical limitations of counting both at low count rates and at low photon energies. Minimum detectable activity over the chest is approx.1.1 kBq (30 nCi) or higher for plutonium-239 and 11 Bq (0.3 nCi) for Americium-241, in a single count of 30 minute counting period. Repeated counts over extended periods of time will increase the reliability of the data and improve the detection limits. Further guidance on design of programme and interpretation of results for internal contamination may be found in references (62) and (63).

CHAPTER 4

PLANNING, ORGANISATION AND PREPAREDNESS

4.1 PLANNING & ORGANISATION

The different types of radiation accidents and their biological consequences in the exposed persons have been described in detail in Chapters 1 and 2. Chapter 2 describes also the triage, prognosis and medical management of radiation casualties. In Chapter 3 the biological and physical dosimetry techniques and the instrumentation used for the assessment of tissue doses and diagnostic evaluation have also been described. For prompt diagnosis and proper treatment of the different types of casualties, it has been recommended that the medical facilities should be planned at four different levels as follows:

1. First-aid post.
2. Personnel Decontamination Centre.
3. Site Hospital.
4. Specialised Treatment Centre

The functions of each type of faoility and the equipment and staff to be provided at each facility have also been described in Chapter 3.

4.1.1 FIRST-AID POST

The first-aid-post in major nuclear installations (e.g. nuclear power station, fuel reprocessing plant, advanced fuel fabrication plant, high-level radioactive waste management plant) should be manned by a properly trained para-medical assistant. The first-aid post has an important role in triage, particularly when a large number of casualties are involved after an accident. For example, in the Chernobyl power reactor accident, out of about 24,000 persons suspected to have been exposed to radiation, 203 persons were identified as having received high doses and requiring hospitalisation. The triage was done essentially on the basis of the prodromal symptoms. The different types of prodromal symptoms, particularly vomiting and diarrhoea, and their use in prognosis, based on onset, intensity and duration of the symptoms, have been discussed in Chapter 3. Suitable criteria should be established and the first-aid assistant should be familiar with these criteria. Other first-aid measures required are attending to life-threatening injury, administration of anti-emetic and symptomatic (sedative, cardiotonic) drugs, administration of prophylactics such as KI tablets, DTPA aerosol etc., simple personal decontamination procedures and proper transportation of the casualties to the site hospital. There should be proper liaison between plant management, particularly the Plant Emergency Director and the Medical Superintendent of the Site Hospital.

4.1.2 SITE-HOSPITAL

The Site Hospital has an important role in receiving and temporary care of the casualties, particularly those showing severe haematopoietic syndrome, pending arrangements for their transportation to the specialised treatment centre. The usefulness of haematological dosimetry, particularly lymphocyte counts, for prognosis of the casualties was discussed in Chapter 3. In the Chernobyl power reactor accident, the Site Hospital conducted about 1000 blood tests (minimum of 2-3 tests for each casualty) during the first 36 hours of their admission at the Site Hospital to confirm the prognosis made at the first-aid post on the basis of prodromal symptoms. The criteria should be established for classification of the casualties on the basis of the haematological findings and the medical personnel responsible for the care of the radiation casualties should be familiar with these criteria. The Site Hospital staff should be familiar with these criteria. The Medical Superintendent of the Site Hospital should also establish suitable arrangements with a cytogenetic laboratory for proper collection of peripheral blood samples from the casualties and their despatch to the cytogenetic laboratory for chromosomal aberrations analysis. It is essential that suitable equipment and facilities and properly trained physicists are available at the Site Hospital to carry out physical dosimetry measurements (external radiation, radioactive contamination), described in Chapter3. The Site Hospital should also have facility and trained medical and para-medical personnel for the care of casualties showing mild haematopoietic syndrome and severe

intestinal or neurological syndromes. The Site Hospital should establish suitable liaison with other hospitals in the neighbourhood to draw additional medical and para-medical personnel or for any assistance (e.g. blood transfusions, drugs, medical supplies) which may be required for medical management of the casualties. It is essential that all these arrangements are formalised and written down in a manual in which the responsibilities of different persons are clearly defined; the manual should also contain the names, addresses and telephone numbers of the persons who are to be contacted in a radiation emergency. Guidance for preparation of such a manual, may be obtained from Ref.64. The manual should be updated periodically.

4.1.3 SPECIALISED TREATMENT CENTRE

Several facilities, equipped with sophisticated instruments and specially trained persons are required for the medical management of casualties showing moderate to severe haematopoietic syndrome or mild intestinal syndrome. These include: (a) Clinical laboratory, cytologic, haematological, biochemical, pathological, neurophysiological tests, as well as medical imaging (radiological as well as non-radiological) procedures for diagnosis, (b) special treatment procedures such as platelet transfusion, bone marrow or foetal liver transfusion, with associated facilities for tissue typing, and (c) post-treatment care of the highest quality including prevention and control of infection, reverse barrier nursing, preparation and supply of sterilised food and drinks, parenteral nutrition etc. The centre should have a panel of medical specialists. It should preferably be a part of an advanced cancer treatment centre, where patients of leukemia and aplastic anemia are treated regularly. Such specialised treatment centres have been established in Medical Division of Oak Ridge Institute of Nuclear Studies, Oak Ridge, USA. International Centre for Radiopathology at Curie Foudation, Paris (WHO Collaborating Centre) and Hospital No.6, Moscow, USSR, as well as in a few other countries. The organisation of the specialised treatment centre at Oak Ridge is shown in Fig. 4.1. The organisation, facilities and services available at the International Centre for Radiopathology have been described in Ref. (63).

4.2 EDUCATION & TRAINING

Physicians, physicists, nurses and paramedical staff, duly trained in occupational radiation medicine are essential for proper management of radiation accidents as well as routine medical surveillance of the radiation workers. Their training must include not only basic nuclear physics, radiation physics, radiobiology and clinical aspects of management of partial and whole body irradiation as well as internal and external radioactive contamination but also practical training or demonstrations in respect of the diagnostic techniques and therapy measures employed for the management of radiation casualties. The technical contents of the training course are given in Appendix-I. The course may be modified suitably for the different categories of personnel and training in various subjects may be imparted either at 'Basic level' or 'Advanced Level'. Table 4.1 shows the recommended scope and level of training in various subjects for the physician, physicists and nursing/paramedical staff. It is essential that all the staff undergo refresher courses periodically in order to maintain the desired level of professional competence on a long term basis.

4.3 PREPAREDNESS

As was mentioned in Chapter 1, radiation accidents are relatively rare occurrences. However, when an accident does happen, the staff at the medical facilities (first-aid post, personnel decontamination centre and the site hospital) should quickly mobilise themselves for proper medical management of the casualties. It is thus essential that the staff of the medical facilities are prepared to handle radiation casualties at all times.

Participation of the medical and para-medical personnel in radiation emergency drills and exercises may be helpful to ensure such preparedness.

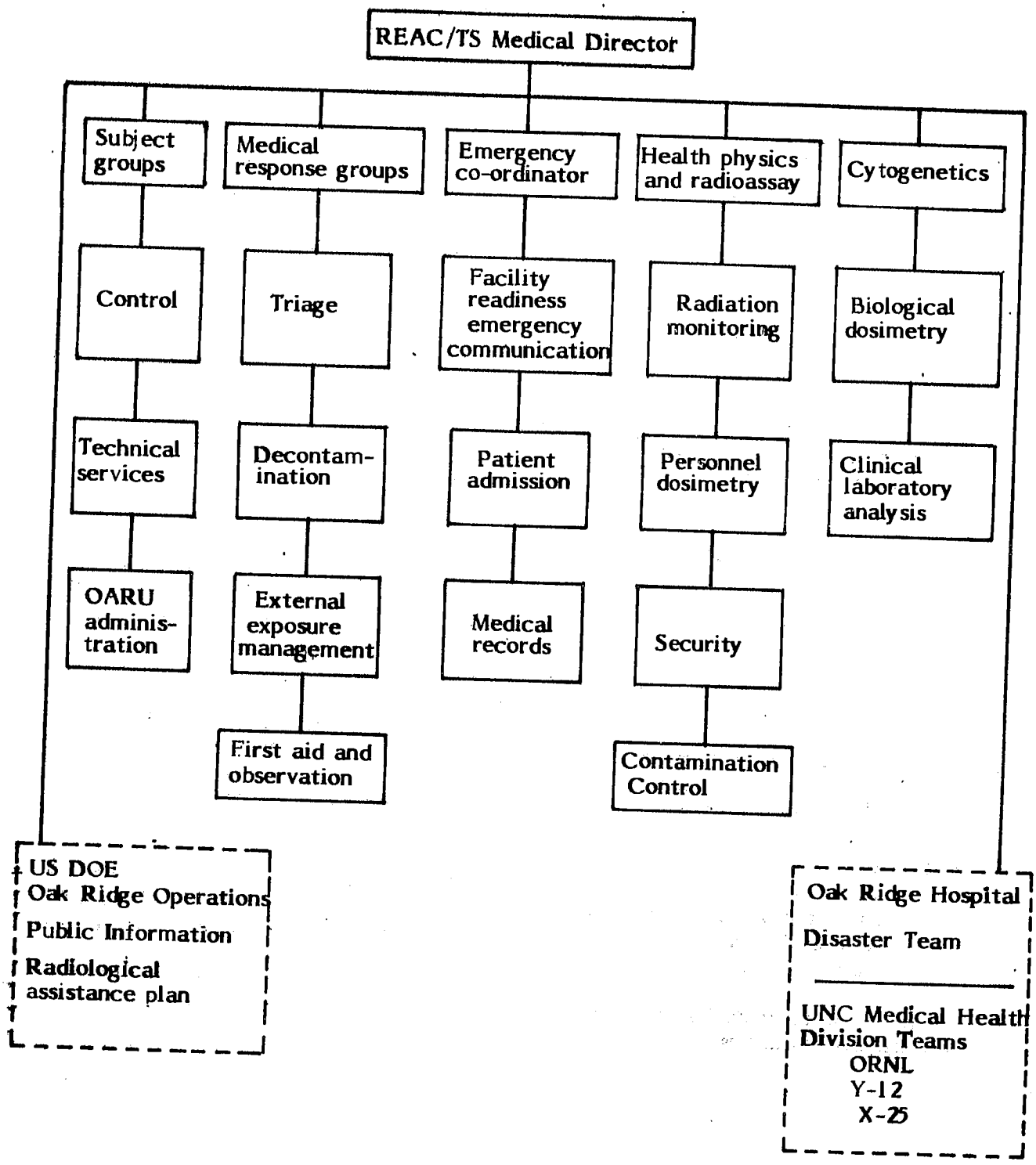

Fig. 4.1 BLOCK DIAGRAM ILLUSTRATING THE ORGANIZATION OF THE REAC/TS EMERGENCY RESPONSE TEAM FOR RADIATION ACCIDENT MANAGEMENT; ORNL, OAK RIDGE NATIONAL LABORATORY; UNC, UNIVERSITY OF NORTH CAROLINA.

Syllabus of the Certificate Course on

RADIATION PROTECTION & OCCUPATIONAL HEALTH

	Subject	No. of lectures
1.	*Basic nuclear physics* : Atomic structure; isotopes; radio-activity - natural & artificial; nuclear reactions - activation; fission ; fusion.	1
2.	*Basic radiological physics* : Nuclear radiation and their properties; interaction of radiation with matter - charged particles, X- and gamma rays, neutrons;	1
3.	*Principles of radiation detection* : Methods of detecting alpha, beta, gamma and neutrons; measuring instruments for dosimetry & survey; whole body counter.	1
4.	*Radiation quantities & units* : Activity; half-life; Dose/absorbed dose, RBE/QF, dose equivalent, weighting factor, effective dose-equivalent; committed dose-equivalent; collective dose.	1
5.	*Sources and characteristics of radiation exposure* : (a) Natural sources; technologically enhanced natural sources; radioactive fallout; (b) nuclear fuel cycle; (c) radiation applications in medicine, industry and other fields. *Radiation protection* in uses of radiation sources.Normal & accidental exposures.	5
6.	*Basic radiation biology* : Direct & indirecteffects; effect of radiation quality; radiation effects on DNA; damage and repair mechanisms; effects on genes and chromosomes; methods of study. *Biological dosimetry:* Dosimetry based on chromosome aberrations and its application; radiation effects on cell organelles.	2
7.	*Radiation effects at cellular level* : Factors affecting cellular response to radiation: cell division & cell cycle; cell differentiation; Law of Bergonie & Tribondeau; oxygen effect; radioprotective and radiosensitizing agents; other factors; cell killing; cell transformation/mutation.	1
8.	*Radiation effects on tissue*: Factors affecting tissue response: composition, repair mechanism, effects of dose-rate and dose fractionation; non-stochastic effects of radiation on skin, bone-marrow, GI tract, gonads, eyes, thyroid, lungs, CNS.	1
9.	*Localised irradiation*: Diagnosis and management of localised skin irradiation; radiation burns; Experience of BARC Hospital: surgical intervention.	2
10.	*Acute whole-body irradiation*: Radiation syndromes-neurovegetative, haematological, gastro-intestinal, neurological; diagnosis and management of acute whole-body irradiation; case studies. Bone marrow transplant: Experience in Tata Memorial Hospital, Bombay.	3
11.	*Effects o f prenatal irradiation*: Pre-implanation phase; organogenesis phase; fetal development phase; effect of radiation on CNS in embryo	

and fetus; peri-natal effects. Guidelines on irradiation of women of reproductive capacity and pregnant women. 1

12. *Normal incidence of cancer*: Morbidity and mortality patterns; classification & staging; etiological factors; human database. *Radiation Carcinogenesis*: high doses at high-dose-rates; low doses at low dose-rates; dose and effect probability relationships; theories & models; risk estimation; probability of radiation causation of cancer; epidemiological studies and problems. Absolute & relative risk estimates. Cancer risk estimates by UNSCEAR, ICRP and BEIR; *Role of radiation in management of cancer.* 3

13. *Radiation induced hereditary effects*: Classification of hereditary disorders. Incidence & prevalence: Data from surveys; data from animal models. Concept of doubling dose and its application to risk estimation. Alternative approaches to risk estimation. Estimates of hereditary detriment due to radiation: UNSCEAR, ICRP, BEIR. 1

14. *Metabolism & toxicity of radionuclides*: Modes of intake; uptake, distribution and turnover; assessment of internal contamination; human data on internal radiation: radon, uranium, thorium, plutonium & americium, tritium, iodine, cesium, strontium. 2

15. *Medical management of contamination*: External decontamination; decorporation of internal contamination. 2

16. *Occupational health surveillance of radiation workers*: Uranium mines; other nuclear fuel cycle facilities; data from medical surveillance of radiation workers: US, UK; "healthy worker effect". Regulatory aspects of medical surveillance. Epidemiological studies of radiation workers. 3

17. *Radiation protection standards*: ICRP system of dose limitation; dose limits for workers and the public; derived and secondary limits; external & internal exposure; levels for use in planning for management of radiation accidents. 1

18. *Index of harm*: Concept, considerations, derivation; comparison of risks in radiation and other industries. 1

19. *Industrial Medicine :* 1

20. Health surveillance for toxic materials in nuclear industry: Be, H_2S and HF 1

21. *Emergency response*: Planning and preparedness 1

Practicals & Clinics

1. Use of radiation survey meters and simple counting instruments.

2. Simple experiments in radiation dosimetry.

3. Demonstration of techniques used for assessment of injury from partial body irradiation: thermography, non-invasive vascular studies, plethysmography, radioisotope scintigraphy.

4. Biological dosimetry and biochemical studies related to acute whole body irradiation - laboratory discussion.

5. Bone marrow transplant facilities - clinic

6. Uptake of radionuclides and bioassay procedures.

7. Clinics - localised irradiation (2 hrs.)

8. Case studies - whole body exposure (2 cases)

Visits (Health physics surveillance & Medical surveillance facilities)

1. Laboratories of Health Physics Division & Division of Radiological Protection. (BARC)

2. Radiation Medicine Centre, Tata Memorial Hospital, Cancer Research Institute & Indian Cancer Registry, Bombay

3. Decontamination Centre (BARC).

4. BARC-Hospital.

5. Radiation processing plants and hot cells (BARC); radioisotope laboratories and radio pharmaceutical plants (BRIT).

6. Research reactors and nuclear power reactor.

7. Beryllium plants.

Audio-visual Education (Films & video cassettes)

1. Living with radiation

2. Nuclear fuel cycle.

3. Radiation protection - 3 parts.

4. Safe handling of radioisotopes: plutonium

5. Safe Transport of radioactive materials.

6. Medical management of radiation accidents.

TABLE 4.1: SCOPE AND LEVEL OF TRAINING FOR MEDICAL AND PARAMEDICAL PERSONNEL FOR RADIATION EMERGENCIES

Subject	Physician	Physicist staff	Paramedical
1. Basic atomic & nuclear physics	+	-	+
2. Basic radiation physics	+	-	+
3. Radiation detectors	+	++	+
4. Radiation quantities & units	+	++	+
5. Sources of radiation exposure (normal & accidental)	+	++	+
6. Radiation dosimetry	+	++	+
7. Basic physiology & anatomy	-	+	-
8. Basic radiation biology	++	+	+
9. Radiation effects at cellular & tissue levels	++	+	+
10. Non-stochastic effects of radiation	++	+	+
11. Diagnosis & management of skin and partial body irradiation.	++	+	++
12. Diagnosis & management of acute whole-body irradiation.	++	+	++
13. Effects of prenatal irradiation	++	+	+
14. Metabolism & toxicity of radionuclides	+	+	+
15. Diagnosis & management of external & internal contamination	++	+	++
16. Stochastic effects of radiation	+	+	+
17. Radiation protection standards	+	++	+
18. Rehabilitation & longterm medical follow-up	++	+	++
19. Medico-legal aspects & Record keeping	++	+	+
20. Practical on radiation detection & measurement	+	++	+
21. Practical on radiation dosimetry	+	++	+
22. Practical on bioassay & whole body counting	+	++	-
23. Clinical investigations on irradiated persons.	++	-	+
24. Cytological & radiopathological studies.	++	-	++
25. Nursing & Nutrition of irradiated persons.	+	-	++

Note: The signs used in the Table denote the follwing :-

- Not applicable + Basic level ++ Advanced level.

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GLOSSARY OF TERMS

1.	Absorbed dose	:	Energy imparted by radiation to unit mass of material. The basic unit is gray (Gy). 1 Gy=1 Joule per kilogram. (Former unit was rad which is equal to 100 ergs per gm.) 1 Gy = 100 rad
2.	Active Area	:	Area in which, under normal working conditions, surface contamination or air contamination is likely to exist;
3.	Activity	:	The number of disintegrations of a radioactive material per second (see Curie and Becquerel).
4.	Allele	:	Alternative forms of a gene found at the same locus on homologous chromosomes.
5.	Aneuploidy	:	A chromosome number different from the normal number.
6.	Ataxia	:	Defective muscular control resulting in irregular and jerky movements.
7.	Autosome	:	Any chromosome other than the sex chromosome. In human beings there are 22 pairs of autosomes.
8.	Becquerel (Bq)	:	The special name for the unit of activity. One becquerel corresponds to one disintegration per second of any radionuclide.
9.	Collective effective dose equivalent	:	Effective dose equivalent to a group of people from a source of radiation. Product of the average effective dose equivalent and the number of persons exposed to the given doses. (The unit of collective dose equivalent is Person-sievert).
10.	Competent Authority	:	Any officer or authority appointed by the Central Government by notification under the Radiation Protection Rules, 1971. At present, Chairman Atomic Energy Regulatory Board is the Competent Authority.
11.	Contamination	:	Undesirable presence of radioactivity in quantities that may be specified as excessive by the competent authority by notification.
12.	Counting or Measurement	:	Measurement of activity, either in a sample or in an individual, using appropriate measuring or monitoring devices.
13.	Curie (Ci)	:	A radionuclide is said to have an activity of 1 Ci if it is transformed at a rate of 3.7×10^{10} disintegrations per second. 1 Bq $= 0.27 \times 10^{-10}$ Ci.
14.	Cytogenetics	:	Branch of genetics concerning the study of chromosomes.
15.	Decontamination	:	Removal of unwanted activity from personnel, surfaces, equipment, etc. to render the affected area safe;
16.	Deletion	:	A loss of a part of chromosome.
17.	Depilation (epilation)	:	Loss of hair
18.	Deterministic	:	Which is sure to occur under appropriate conditions.
19.	Diploid	:	Cells which contain two sets of chromosomes as in the case of human somatic cells.
20.	Direct effect of radiation	:	Damage caused by direct absorption of energy by critical targets in the cell.
21.	Disposal	:	Release of any material to the environment in a manner leading to loss of control over the future disposition of radionuclides contained therein.

22. Dominant : A trait which is expressed in individuals who are heterozygous for a particular gene.

23. Dominant lethal mutation : A genetic alteration in germ cells which renders the conceptus non-viable.

24. Dose : Energy absorbed in matter from ionising radiation per unit mass of the material at the place of interst. The special name of SI unit of dose is gray (Gy). 1 Gray = 1 Joule per kilogram.

25. Dose Equivalent : The quantity obtained on multiplying the absorbed dose in tissue by appropriate weighting factors to correct and/or normalise for variation in the degree of biological effect produced by the same dose of different ionising radiations or under different irradiation conditions. The dose equivalent is used for radiation protection purposes only. The unit of dose equivalent is sievert (Sv) when the absorbed dose is expressed in gray. However, see Addendum for equivalent dose.

26. Dosimetry : Operations and measurements performed in connection with (a) the determination of radiation dose,(b) dose distribution in the irradiated volume and (c) measurements related to operational limits.

27. Doubling dose : The dose which induces the same number of mutations as spontaneous mutations.

28. Effective dose equivalent : Quantity obtained by multiplying the dose equivalent to a tissue by the appropriate risk weighting factor for that tissue expressed in sievert. However, see Addendum for effective dose.

29. Electron volt : Quantity of energy equivalent to 1.6×10^{-19} J.

30. Fission products : Nuclides or radionuclides generated by the splitting of a fissionable material as a result of nuclear fission (^{137}Cs, ^{90}Sr, ^{131}I, ^{85}Kr etc)

31. Fixed erythema : Reddening of skin which appears after 2-3 weeks of exposure to large doses of radiation, caused mainly by failure of arterioles.

32. Free radical : An atom or group of atoms which have unpaired electrons and hence have very high chemical reactivity (e.g. H°, OH°, HO°_2 RO°_2 etc.)

33. Gamma ray : Electromagnetic radiation emitted by radionuclides (^{60}Co, ^{137}Cs, ^{192}Ir etc.)

34. Gene : A part of the DNA molecule which codes for a specific polypeptide chain. A unit of inheritance.

35. Genetic disorders : Diseases, anomalies and mal-formations caused by mutations in the germ cells.

36. Genetic equilibrium : A state where the rate of induction of mutation and rate of elimination becomes same. Generally takes 5-10 generations after exposure to a specific agent.

37. Half Life : Time in which the activity of a particular radionuclide reduces to half the original level. "Biological half life" is the time required to eliminate half the activity from the human body through excretion processes. "Physical half life" is the time in which activity decays to half its value due to disintegration of radiomuclides. The combined effect of both processes is measured as "effective half life" in an organ.

38. Haploid : Cells with one set of chromosomes (23 in human gemete).

39. Hemizygous : A term used to describe the genotype of a male with regard to X linked trait, since males have only one chromosome.

40. Heritability : The proportion of the total variation of a character attributable to genetic as opposed to environmental factors.

41. Heterozygote : An individual who possesses two different alleles at one particular locus on a pair of homologous chromosomes.(Homozygote has the same alleles)

42.	High LET radiations:		Radiations which are densely ionizing e.g.alpha rays and accelerated heavy charged particle beams.
43.	Indirect effects (of radiation)	:	Damage caused by the absorption of radition in the vicinity of a critical site. (In cells,indirect effect is brought about by free radicals and molecular products)
44.	Ionisation	:	A process whereby a neutral atom or a group of atoms acquires an electrical charge leading to the production of ions.
45.	Isotope	:	Nuclide with the same number of protons but different in the number of neutrons.
46.	Karyotype	:	The number, size and shape of the chromosomes of a somatic cell. A photomicrograph of an individual's chromosomes arranged in a standard manner.
47.	Latent period	:	The period between the exposure to a disease causing agent or process and the appearance of symptoms, e.g. the period after prodromal symptoms of high radiation doses and appearance of acute radiation syndrome or a later date malignancy etc.
48.	Kerma	:	The energy, per unit mass, transferred by gamma rays, X-rays or neutrons in the form of kinetic energy of secondary charged particles at the point of interest in an irradiated medium. If the irradiated medium is air, the corresponding kerma is called air kerma.
49.	LD 50(60) dose	:	Radiation dose (acute) which induces lethality among 50% of the exposed individuals within 60 days, (for human beings the best estimate is 4-5 Gy).
50.	Low LET radiation	:	Gamma rays, X-rays or beta rays.
51.	Meiosis	:	Cell division process which occurs during gametogenesis resulting in the formation of haploid gametes (also called reduction division).
52.	Mental retardation	:	Reduced intelligence resulting in inability to form simple sentences, solve simple arithmatic problems, take care of oneself,dependent and requiring institutionalization. IQ generally below 70(KOGA)score.
53.	Mitosis	:	Type of cell division which occurs in somatic cells.
54.	Multifactorial	:	Inheritance controlled by many genes with small additive effects (polygeni) plus the effects of the environment.
55.	Monitoring	:	Periodic or continuous determination of the amount of radiation or contamination, for the purpose of health protection. For this purpose, determination of the exposure rate in an area is called"area monitoring" and determination of the dose received by a person is called "personal monitoring".
56.	Mutagen	:	Agents which induce mutations e.g. chemicals, radiation,heat, etc.
57.	Mutation	:	A change in the genetic material, either of a single gene (point mutation) or in the number or structure of chromosomes. When a mutation occurs in the gametes it is inherited.
58.	Mutation rate	:	The number of mutations at anyone particular locus which occurs per gamete per generation.
59.	Non-disjunction	:	The failure of two members of a chromosome to separate during cell division resulting in both chromosomes going to the same daughter cell. This leads to aneuploidy. Such numerical mutations in germ cells cause diseases like Down's Syndrome, Pateau's Syndrome and Edward's Syndrome.
60.	Non-stochastic effects	:	Those effects which occur above a certain threshold dose. These effects are deterministic with an increasing severity with dose. However, see Addendum for deterministic effects.

61.	Nucleus	:	A part of the cell which contains the chromosomes.
62.	Operator gene	:	A gene which switches on adjacent structural genes. (Operator gene+structuralgenes= operon).
63.	Phenotype	:	The appearance (physical, biochemical and physiological) of an individual which results from the interaction of the environment and his genotype.
64.	Point mutation	:	Involves a change in very small part of DNA molecule.
65.	Pre-implantation period	:	First few days of conception until the implantation of embryo on the uterine wall (generally 6-8 days in human beings).
66.	Pre-meiotic cells	:	Spermatogonia, oocytes.
67.	Prodromal syndromes:		Sickness which preceeds later effects. Following acute exposure to radiation doses above 1 Gy, prodromal syndrome is characterised by nausea, vomiting, diarrhoea, fatigue, fever, headache etc. which manifests within the first 1-6 hours following exposure.
68.	Rad	:	Unit of absorbed dose, equivalent to an energy absorption of 10^{-2} J.kg^{-1} (or 100 ergs/gm). Now rad is replaced by the unit gray. 1 gray = 100 rad.
69.	Protective barrier or Shielding	:	A barrier of radiation attenuating material used to reduce radiation levels.
70.	Radical scavenger	:	Substance which reduces the indirect effects of radiation by removing the free radicals e.g. SH compounds.
71.	Radiation protection survey or Survey	:	An evaluation of safety using appropriate radiation measuring instruments.
72.	Recessive	:	A trait which is expressed in individuals who are homozygous for a particular gene but not in those who are heterozygous for the gene.
73.	Radioactive Waste	:	Any waste material containing radionuclides in a concentration which prohibits its disposal as ordinary waste.
74.	Radiological Safety Officer (R.S.O.) or Health Physicist	:	A physicist who is so designated and who is qualified to discharge the functions related to radiation protection.
75.	Regulator gene	:	A regulatory gene synthesizes a repressor substance which inhibits the action of a specific operator gene.
76.	Relative biological effectiveness (RBE)	:	It is a factor expressing the relative effectiveness of radiations, with differing linear energy transfer (LET) values, in producing a given biological effect. It is used in radiobiology.
77.	Rem	:	Unit of dose equivalence, since replaced by the sievert. 1Sv=100 rem
78.	Reproductive death	:	The loss of indefinite proliferative ability of cells of dividing cell systems.
79.	Sister chromatid exchange	:	Exchange of genetic material between two chromatids of any particular cromosomes.
80.	Somatic effects of radiation.	:	Damage that is apparent during the life-time of the organism.
81.	Stem cells	:	(Precursor cells) least differentiated cells with indefinite capacity to proliferate. Present in organs where the cell renewal takes place continuously e.g. skin, bone marrow, testis, intestinal crypt etc.
82.	Stochastic effects	:	Those effects which are probabilistic in nature and occur without a threshold dose. The probability of incidence increases with dose. (e.g. cancer and genetic diseases).
83.	Teratogen	:	An agent believed to cause congenital abnormalities.

84.	Tinea capitis	:	Ring worm of the head.
85.	Translocation	:	The transfer of genetic material from one chromosome to another.
86.	Trisomy	:	A chromosome additional to normal complement, such that one chromosome is represented thrice in a somatic cell.
87.	X-linked	:	Genes carried on X-chromosomes.
88.	Unsealed source	:	A source which is likely to produce contamination under normal conditions of use.
89.	Weighting Factor	:	The factor which represents the proportion of risk resulting from irradiation of the tissue under consideration to the total risk when the whole body is irradiated uniformly to the same dose. Individual organ doses are multiplied with their respective weighting factors and added to assess "effective whole body dose equivalent". However, see Addendum for tissue weighting factor.
90.	Zygote	:	Fertilized egg.

ADDENDUM

When the present Guide was being printed, the latest 'Recommendations of the International Commission on Radiological Protection' were published, as ICRP Publication - 60 (1991). This publication now replaces ICRP's earlier 'Recommendations' contained in its Publication-26 (1977). In so far as it concerns this Guide, the following changes made by ICRP are important: (a) Change in the names of several dosimetric quantities, (b) Change in quantities related to radiation quality and tissue weighting factors,(c) Probability-coefficients for stochastic effects, and (d) The dose limits recommended for both radiation workers and members of the public. The new recommendations of ICRP will soon be adopted in the practice of radiation protection. The present guide will accordingly require certain changes, mainly in Chapter 2. The following information is, therefore, provided in this Addendum, which should be referred appropriately:

1. The quantity 'dose equivalent' is now called **equivalent dose** ; the unit of equivalent dose remains sievert (Sv) as before.

2. The quantity 'effective dose equivalent' is now called **effective dose**; the unit of effective dose remains sievert (Sv) as before.

3. The quality factor, Q, is now called **radiation weighting factor**; the new values of various radiation weighting factors, W_R, given in Table-A below replace the values of Q given in Table 2.1.1 in this Guide.

4. The 'non-stochastic effects' of radiation are now called **deterministic effects** of radiation. (See Table 2.3.1 in the Guide).

5. The term 'weighting factor' W_T, is now called **tissue weighting factor**; the new tissue weighting factors, W_T for various organs given in Table-B below replace the values given in Table 2.1.2 in this Guide.

6. The nominal probability coefficients for fatal cancers and hereditary effects (See Tables 2.2.1 and 2.2.2 in the Guide) have been modified as given in Table-C below.

7. The **dose limits** for occupational exposure and for exposure of the public (see last paragraph of Section 2 in Chapter 2 of the Guide) have been revised as given in Table-D below.

TABLE - A : RADIATION WEIGHTING FACTORS

Type and energy range		Radiation weighting factor, W_R
Photons, all energies		1
Electrons and muons, all energies		1
Neutrons, energy	< 10 keV	5
	10 keV to 100 keV	10
	> 100 keV to 2 MeV	20
	> 2 MeV to 20 MeV	10
	> 20 MeV	5
Protons, other than recoil protons, energy	> 2 MeV	5
Alpha particles, fission fragments, heavy nuclei		20

TABLE - B: TISSUE WEIGHTING FACTORS

Tissue or organ	Tissue weighting factor, W_T
Gonads	0.2
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder*	0.05

* The remainder is composed of: adrenals, brain, small intestines, kidney, muscle, pancreas, spleen, thymus and unterus i.e. the organs that are likely to be selectively irradiated. When a single one of the remainder tissues or organs receives an equivalent dose in excess of the highest dose in any of the twelve organs for which weighting factors are specified, a weighting factor of 0.025 is applied to that tissue or organ and a weithting factor of 0.025 to the average dose in the rest of the remainder.

TABLE-C : NOMINAL PROBABILITY COEFFICIENTS FOR STOCHASTIC EFFECTS

Biological effect	Exposed population	Probability coefficient ($10^{-2}Sv^{-1}$)
Fatal cancer	Adult workers	4.0
Fatal cancer	Whole population	5.0
Serious hereditary effects (weighted)	Adult workers	0.6
	Whole population	1.0

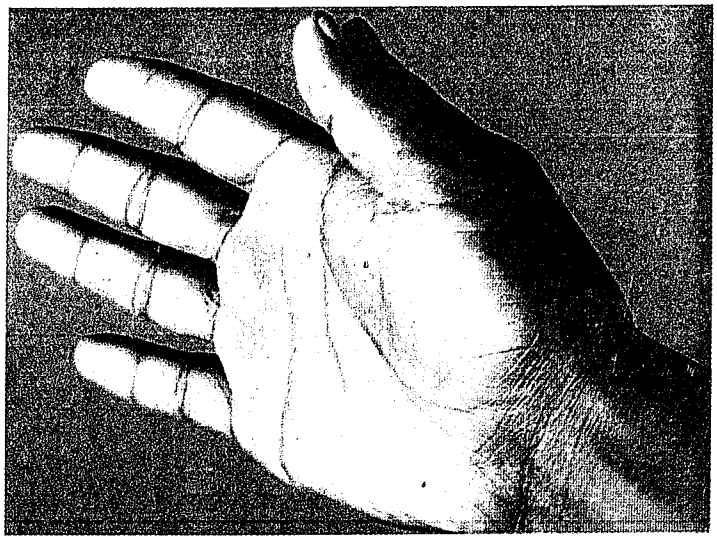
TABLE -D : DOSE LIMITS OF ICRP (1991)

Application	Dose Limit***	
	Occupational	Public
Effective dose	20 mSv per year (averaged over a period of 5 years)*	1 mSv per year**
Annual equivalent dose in :		
(a) the lens of the eye	150 mSv	15 mSv
(b) the skin	500 mSv	50 mSv
(c) the hands and feet	500 mSv	--

* Effective dose should not exceed 50 mSv in any single year and 100 mSv in 5 years. However, abdomen of a pregnant woman should not receive a surface dose of more than 2 mSv, after the pregnancy has been declared.

** Effective dose higher than 1 mSv in a year is permitted in special circumstances, provided average over 5 years does not exceed 1 mSv per year.

*** To prevent deterministic effects in the case of localised exposures, a limit of 500 mSv, averaged over an area of not more than 1 cm^2, regardless of the area exposed, is recommended for annual occupational exposure. For members of the public a reduction factor of 10 is recommended.



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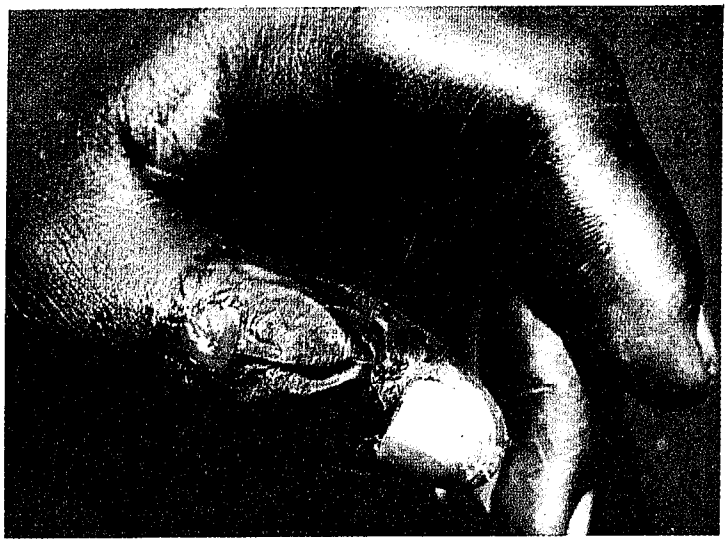

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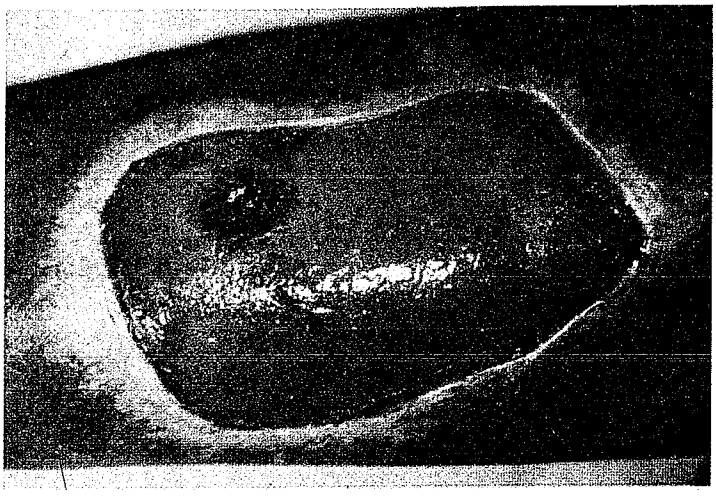

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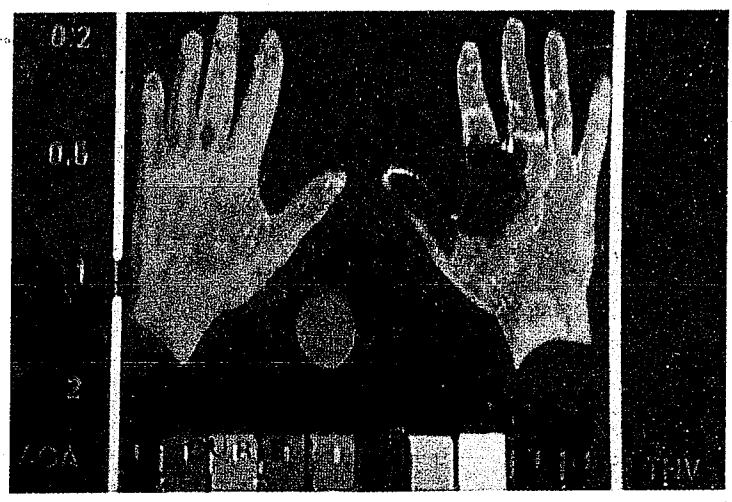
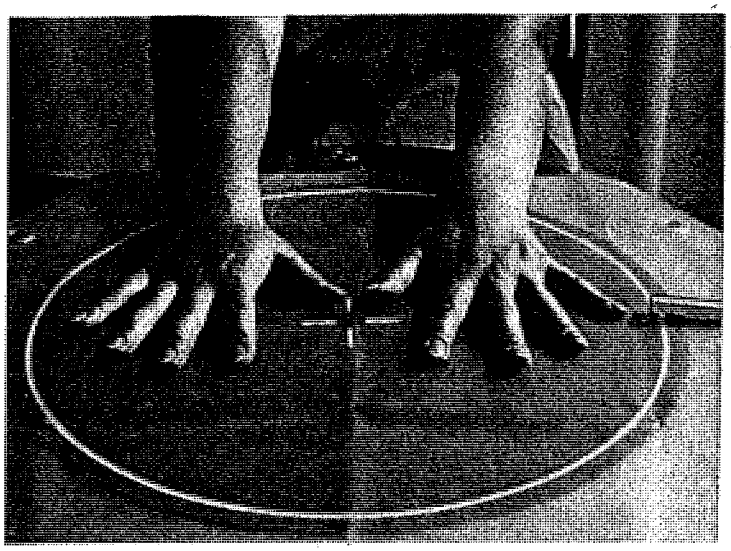


4(a)

1. Erythema of the palm after exposure to Co-60 radiography source (dose about 6 Gy)
2. Ulceration of thumb after exposure to Co-60 radiography source (dose about 20 Gy)
3. Radionecrosis of thigh after exposure to Ir-192 radiography source (dose above 25 Gy)

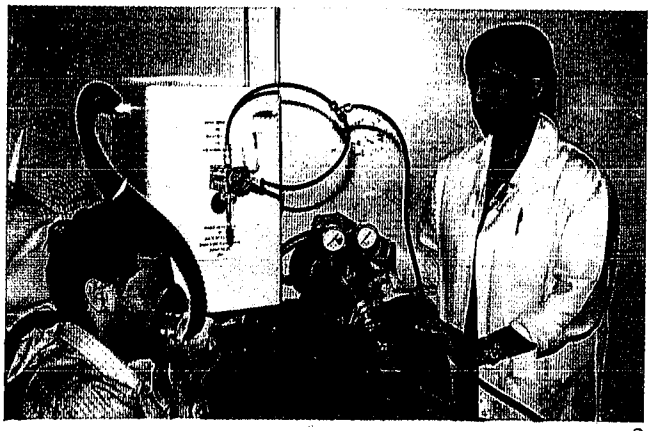
4(a) Plate thermography: localised irradiation of the extremities

4(b) Scintillation camera: evaluation of vascular and bone changes



4(b)

5



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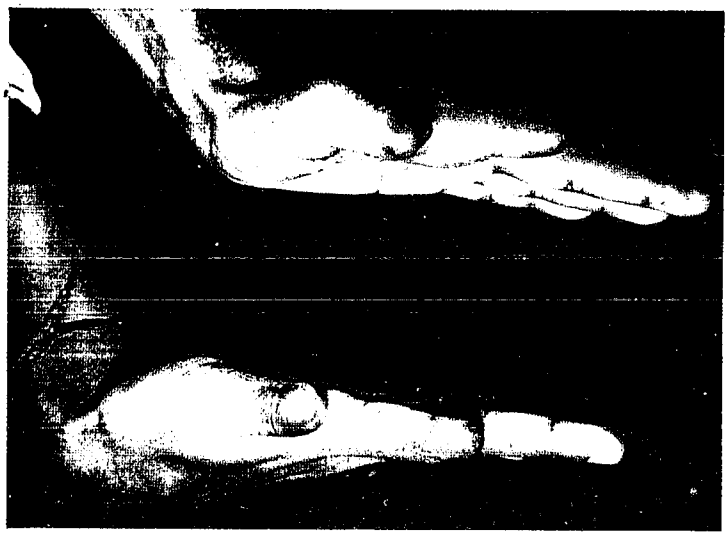

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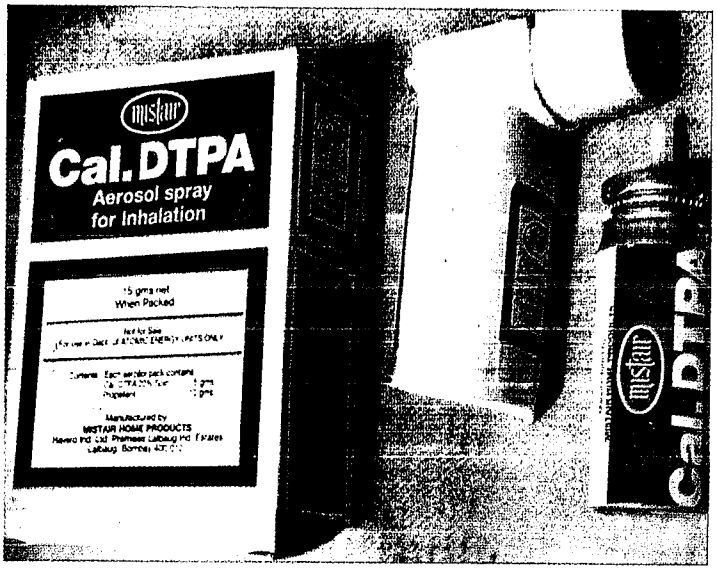

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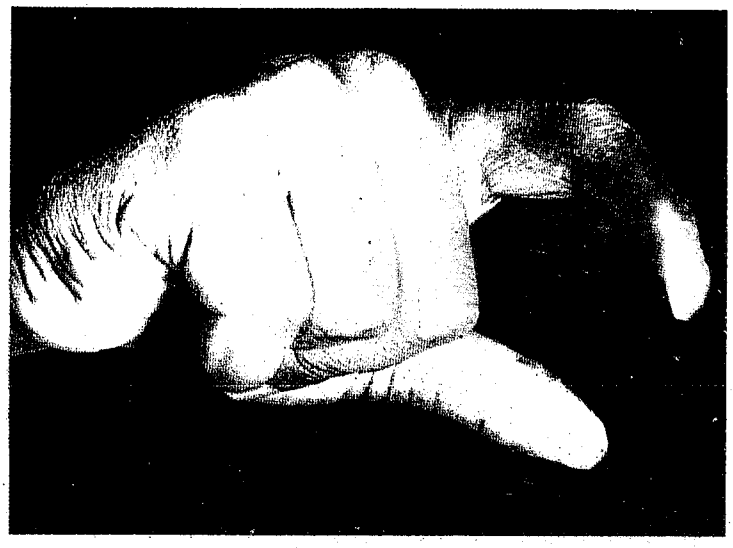
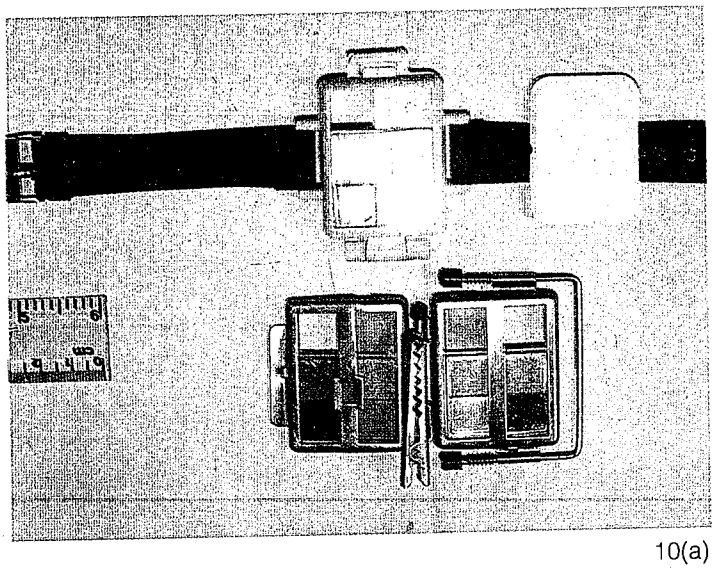
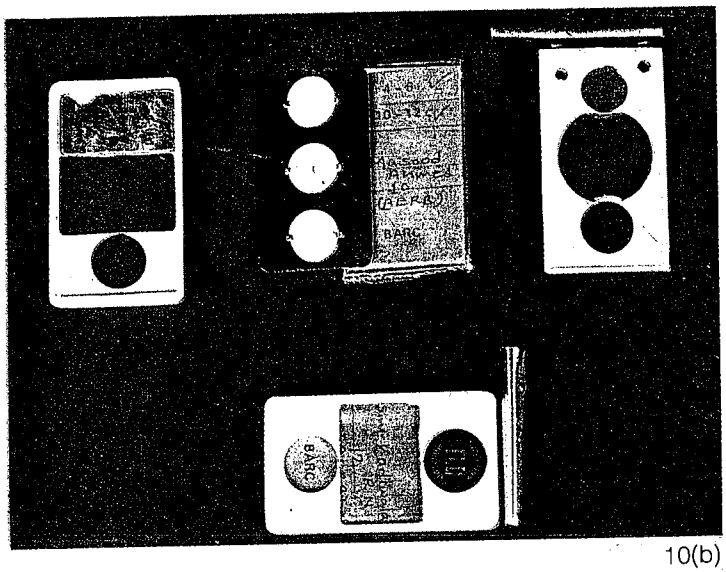


7

5. Gangrene of thumb and index finger of both the hands, following exposure to Ir-192 radiography source, before treatment
6. Hands of the patient, shown in photograph 5, after amputation of the affected fingers.
7. Gangrene of index finger after exposure to Ir-192 radiography source (dose about 30 Gy)
8. Aerosol generation/inhalation system of Bhabha Atomic Research Centre
9. DTPA aerosol inhaler



10(a)



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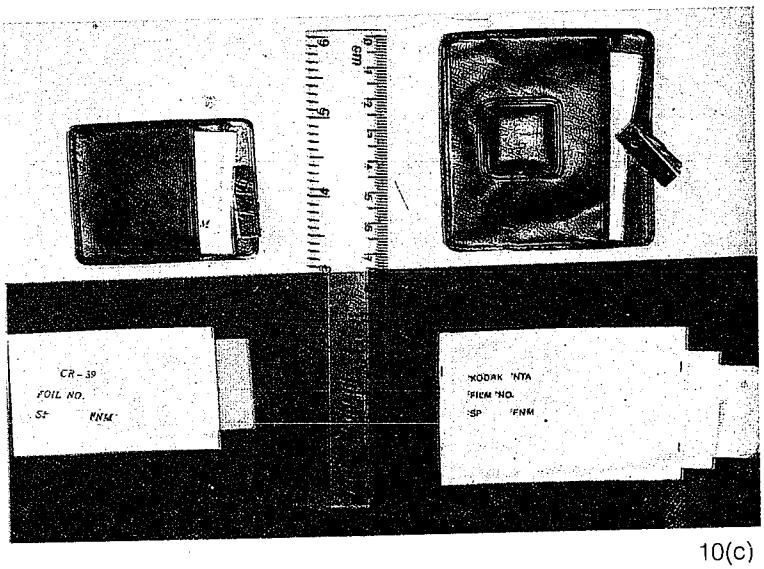

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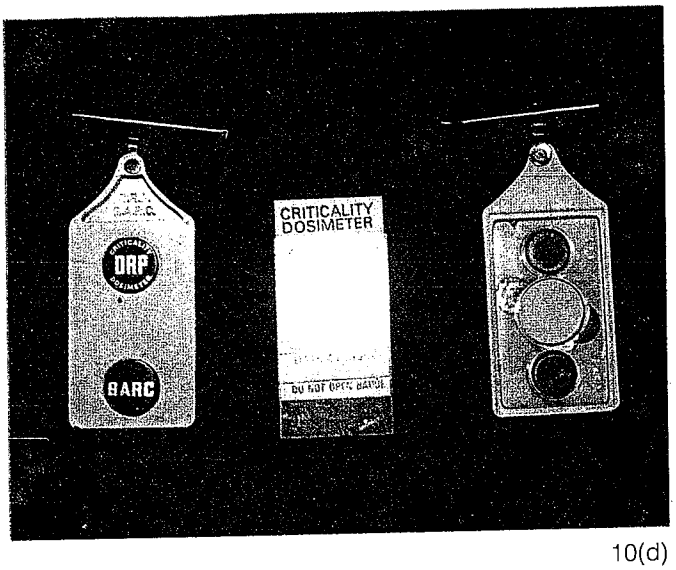


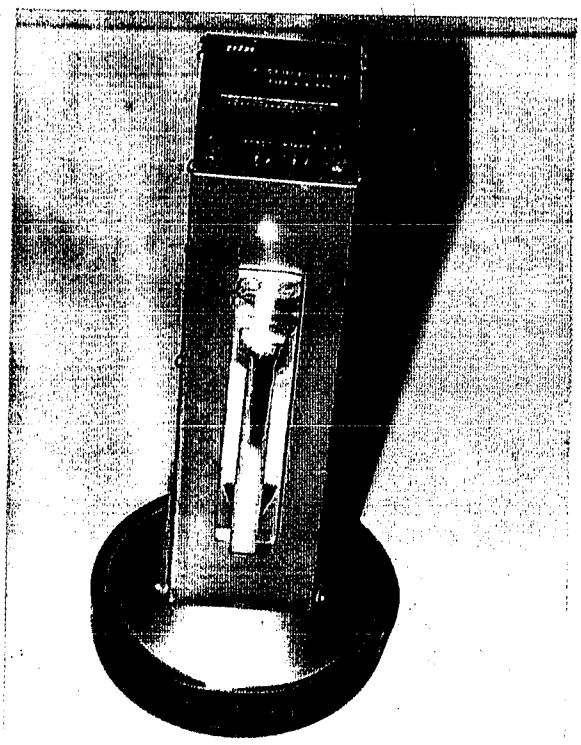
10(d)

10. Different types of dosimeters used for personnel monitoring (see section 3.3.2 to 3.3.7)

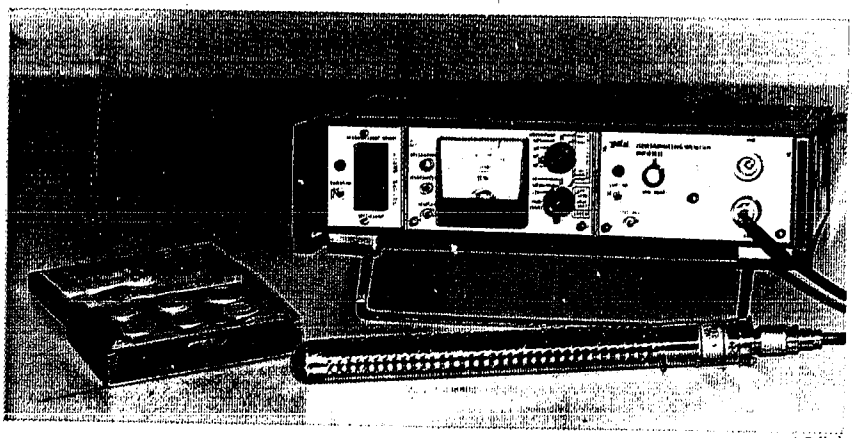
    (a) Film badge with holders, (b) TLD badges (parts and assembled),(c) Neutron badges and holders, (d) Criticality dosimeter.

11. Use of phantom for reconstruction of an acute irradiation accident (see section 3.3.7)

11



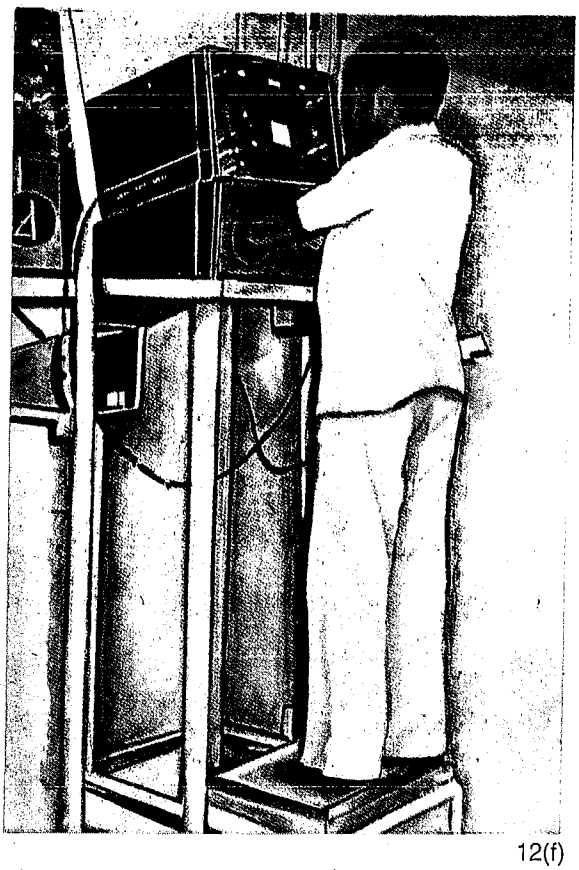
12(a)



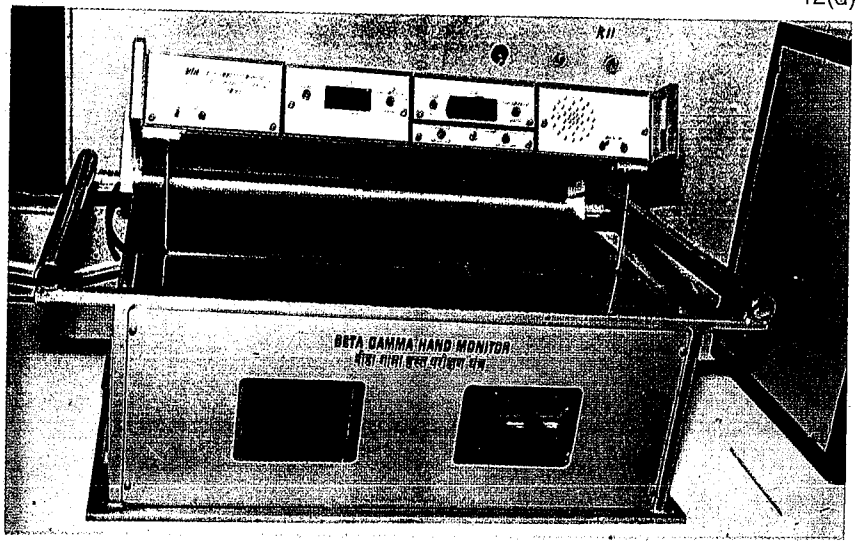
12(b)

12(c)

12(d)



12(f)

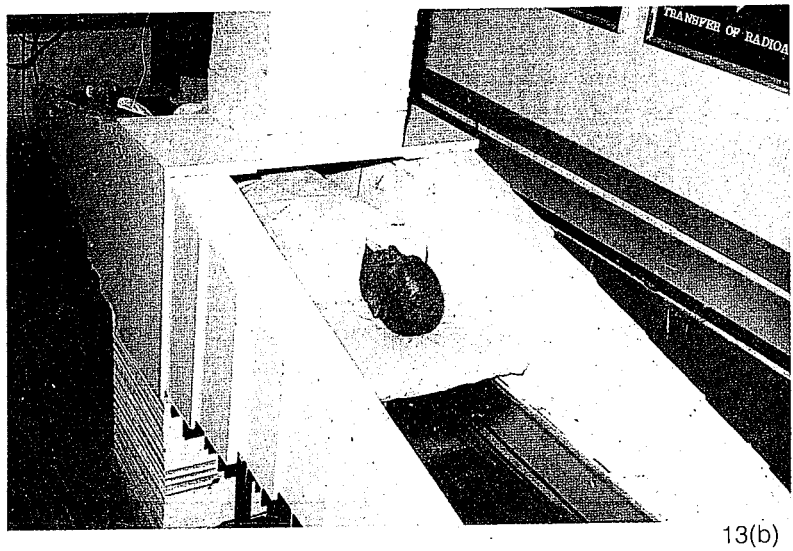


12(e)

12 Various types of contamination monitors. (see section 3.4.1)

(a) Alpha contamination monitor
(b) Beta-gamma contamination monitor
(c) Portable gamma field monitor
(d) Portable beta-gamma survey meter
(e) Beta-gamma hand monitor
(f) Beta-gamma hand and foot monitor

13(a)



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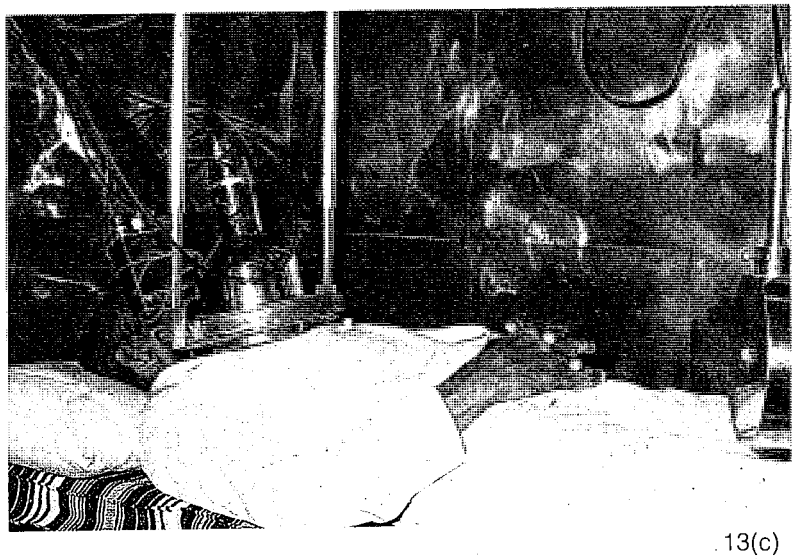
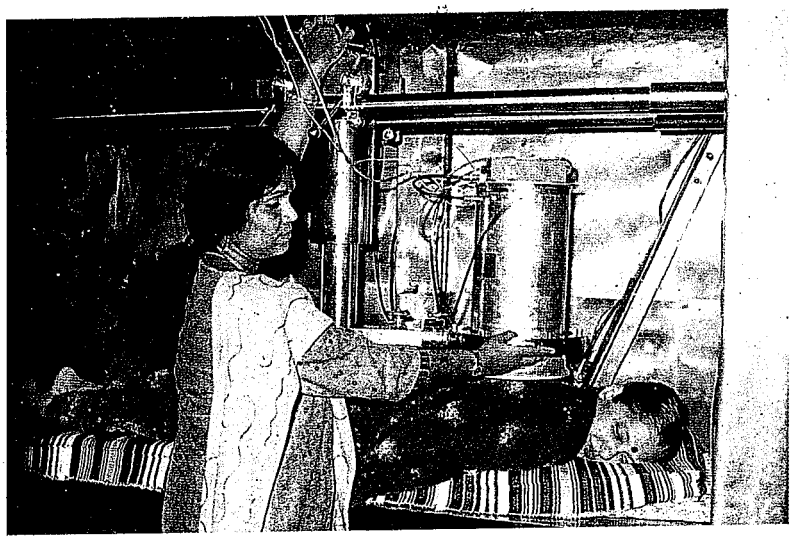


13(c)



13(d)

13. Monitoring for internal contamination

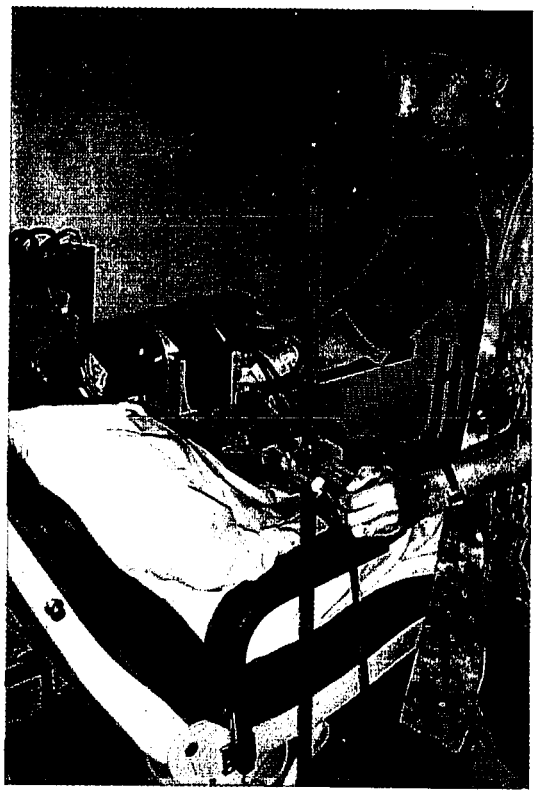
(a) A worker being monitored for radioactive contamination inside his body

(b) A worker being linearly scanned to locate any radioactive nuclide in his body.

(c) Monitoring for uranium contamination in respiratory system.

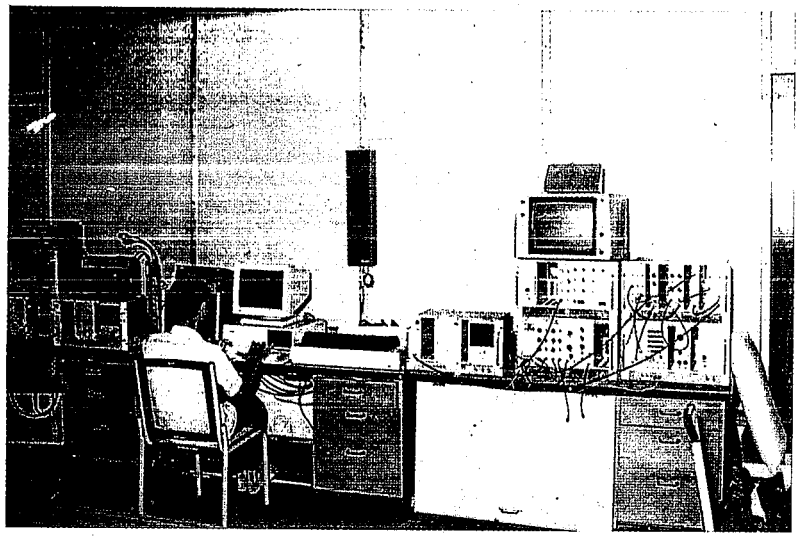
(d) Monitoring for Pu/Am contamination in the lungs of a female worker.

(Continued on next plate)



13(e)

13(f)



13(g)

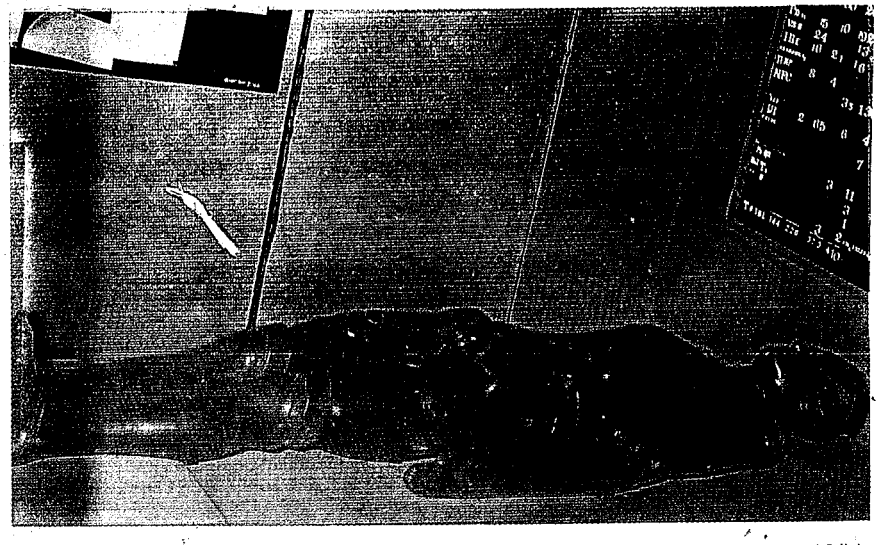
13 Monitoring for internal contamination
(Continued from previous plate)

(e) Thyroid monitoring for I-125 contamination.

(f) Thoron breath monitoring for thorium contamination in the lungs.

(g) Equipment in a direct in-vivo radio-activity counting laboratory.

(h) A phantom used for calibration of in-vivo counters.



13(h)