GUIDANCE MANUAL

Medical Management of Individuals Involved in Radiation Accidents

PART 1 of 3

Preface

Contents

Section 1

TECHNICAL REPORT SERIES No. 131

AUSTRALIAN RADIATION PROTECTION AND NUCLEAR SAFETY AGENCY

ARPANSA

AUSTRALIAN RADIATION PROTECTION AND NUCLEAR SAFETY AGENCY

Manual on the Medical Management of Individuals Involved in Radiation Accidents

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PREFACE TO FIRST EDITION

The purpose of this Manual is to assist physicians, particularly those in accident and emergency departments of hospitals, nurses and medical and health physicists in the medical management of individuals who have been involved in radiation accidents. Medical administrators should also find it helpful in planning for action to be taken within a hospital when such individuals are admitted to the hospital. It has been prepared following two courses on radiation accidents which were presented by the US Radiation Emergency Assistance Centre and Training Site (REAC/TS) of the Oak Ridge Associated Universities (ORAU), with some Australian participation. The courses were sponsored by the Australian Radiation Laboratory; the first - "Medical Planning and Care in Radiation Accidents", was held from 27-31 August, 1990 in collaboration with the Peter MacCallum Cancer Institute at the Peter MacCallum Hospital, Melbourne and the second - "Health Physics in Radiation Accidents", was held from 3-7 September, 1990 in collaboration with the Natural Disasters Organisation at the Australian Counter Disaster College (ACDC), Mt. Macedon.

The first course was designed primarily for accident and emergency department physicians in major hospitals but was also planned to be helpful to radiotherapists, nuclear medicine physicians, nurses and medical physicists. It enabled the participants to more effectively manage people who are involved in radiation accident/emergency situations and to take into account the risks arising from different radiation sources. In addition, it gave them a better appreciation of the essential elements of a hospital's response plans for radiation emergencies and the adoption of disaster plans for multiple casualties.

The second course was designed primarily for health physicists and medical physicists, but was also planned to be helpful to others with health physics backgrounds who might be involved in planning for radiation accident or emergency situations. It enabled the participants to become aware of the different diagnostic and treatment modalities and gave them a better appreciation of pre-hospital and hospital emergency plans. In turn, they should be able to organise a more appropriate health physics response.

One of the underlying considerations in selecting applicants for the courses was the need to have groups of people in each capital city of

Australia who could plan for and cope with the protection requirements and medical care of people involved in radiation accidents and emergencies. In addition, because the Australian Radiation Laboratory and the Peter MacCallum Cancer Institute form, jointly, a WHO Collaborating Centre for Radiation Protection and Emergency Medical Preparedness and Assistance, several countries in the Region were invited to participate so that they could obtain first hand experience in the management of patients from radiation accidents.

This Manual is concerned with accidents or emergencies which involve sources of ionising radiation. It does not cover other forms of radiation such as non-ionising radiation (ultra-violet, light, radiofrequency radiations), heat, etc. Most radiation accidents have involved individuals either at the workplace or with medical misadministrations; they have received external exposure from X-ray or γ-ray sources or have been contaminated with radioactive material. A few members of the public have also been involved through misadventures with radioactive sources although these may not be thought of as accidents; more commonly, they are referred to as "incidents". For the purpose of this Manual, there is no differentiation between an accident and an incident, as the medical care required is the same in both situations.

There have been very few accidents in Australia where individuals have been seriously affected by radiation. However, it has been reported that in many countries there has been a two to three-fold increase in the number of people who have contact with radiation sources in their work activities and this number could double by the end of the century. This gives an increased potential for accidents to happen. Production of a Manual such as this does not imply that there will be an increase in the number of serious accidents in Australia in the future. It simply recognises the fact that although some accidents have occurred in the past, albeit very small in number, and with the present controls and safeguards in place, this should continue to be the case, there is a need for some basic training to be in place to cope with those situations, should they occur.

A lot of the material given in this Manual includes that given at the two courses presented by Dr Robert Ricks, Director of REAC/TS, Dr Mary Ellen Berger, Assistant Director of REAC/TS and Dr Shirley Fry, Director of ORAU’s Centre for Epidemiologic Research and Assistant Chairman for ORAU’s Medical Sciences Division. Their willingness for this material to be included in the Manual

is acknowledged and greatly appreciated. In a manual such as this, it is not possible to go into too much detail and it is recommended that the publications listed in the Bibliography and some of the papers issued at the courses and reprinted at the back of the Manual be consulted for detailed information. In addition, two video recordings with associated booklets are available and are very useful in demonstrating radiation protection techniques to be used. These are "Hospital Emergency Department Response to Radiation" and "Pre-hospital Response to Radiation Accidents".

Useful information on the management and care of individuals involved in radiation accidents was given in 1968 by the' National Health and Medical Research Council in its publication "Notes on Medical Procedures for Radiation Accidents and Radioactive Contamination". This document is under revision; when finalised, it should be read in conjunction with this Manual for background information to assist in the practical implementation of procedures.

This Manual is being widely circulated so that its contents can be drawn on and utilised in planning the requirements for managing and caring of people who have been in radiation accidents. It is hoped that it will also be used as a training vehicle for new people who might be involved in such care in the future. Reading the Manual once is not sufficient in itself to enable people to cope with accident situations. The material enclosed needs to be understood and put into trial runs so that when an accident does occur, everyone is able to cope with it properly. From time to time, new material will become available and it is proposed to update this Manual whenever warranted by this new material.

PREFACE TO SECOND EDITION

The first edition of this Manual was prepared by Tom Swindon and was published in September 1991 by the former Australian Radiation Laboratory. The Manual has proved to be a very useful document for use in emergency medical departments in Australian hospitals. The first edition is no longer available and the Australian Medical Disaster Co-ordination Group requested the preparation of revised edition, as part of the emergency planning for the Sydney 2000 Olympics.

In February 1999 the Australian Radiation Laboratory and the Nuclear Safety Bureau were combined to form a new regulatory body, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). ARPANSA and the Peter MacCallum Cancer Institute, form a WHO Collaborating Centre for Radiation Protection and Radiation Emergency Medical Assistance, with membership of the WHO Radiation Emergency Medical Preparedness and Assistance Network (REMPAN).

The production of the revised second edition of the Manual has been a joint effort between ARPANSA and the Peter MacCallum Cancer Institute. The Manual has undergone extensive cosmetic and format changes to improve readability. The updated material includes:

- the treatment of radiation injuries,
- the biokinetics of internal radioactive contamination, and
- the relevant organisations and State Authorities.

Once again, the advice and assistance of Dr Robert Ricks and his team at REAC/TS is gratefully acknowledge, both in the preparation of this revision and for allowing the use of the REAC/TS material, in particular, the *Guidance for Radiation Accident Management,* which has been included as part of this revised edition. The Guidance document, although brief and didactic, provides concise information on current best practice for radiation accident management. The original can be found at the REAC/TS WEB site at www.orau.gov/reacts.

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23 August 2000

CONTENTS

SECTION 1

SECTION 2

APPENDICES

1.0 RADIATION ACCIDENTS: THEIR CAUSES AND INCIDENCE

Accidents occur in all walks of life, some serious and some minor, but those in which radiation is involved seem to cause more concern and fear than in almost all other types of accidents. With most other accidents, the effects become obvious immediately or within a very short period of time after the accident.

Early symptoms arising from a radiation accident are rare; they only occur if the radiation 'exposure is extremely high. Rather, the consequences, if any, will become manifest many years later, in the form of cancer. In many instances, however, there are no consequences; if cancer does become manifest, only very rarely can it be directly correlated or associated with the accident.

There is also the fear of hereditary effects arising, but there has been no evidence of these occurring in mankind up to the present time. However, it is not uncommon for individuals to live for many years in the fear that something like cancer or hereditary effects will occur as a consequence of their having been involved with radiation in an accident; this fear may ultimately affect their general health.

Because it has been known for a very long time that radiation produces biological effects, controls have existed for many decades in the workplace to ensure the safety of people using X-ray equipment, irradiation facilities and radioactive sources. These controls have been extended over the years to include the safety of members of the public from such radiation sources. Nowadays, many equipment and facilities have built-in safety devices to prevent the unnecessary or accidental exposure of individuals but these are not always foolproof. As a result of all the controls, there have been relatively few radiation accidents giving rise to early symptoms or which could be associated with later cancers in individuals involved in them.

An accident is generally thought of as an unforeseen event caused by an equipment fault, an infringement of instituted controls or procedures or some other agent which is beyond the control of individuals who are either involved in the event or responsible for whatever causes the accident.

Such events can lead to increased hazards to health. Increased hazards to health may also arise in other situations, such as inappropriate disposal of waste materials, individuals being in hazardous areas or handling hazardous materials without being aware of those hazards, terrorist attacks, etc. These are sometimes referred to as incidents, but the effects on the health of the involved individuals are the same sort as those arising in individuals who are involved in accidents. Accordingly, the same level of medical care is needed and all such situations are included in the term "radiation accident" in this Manual.

Radiation accidents may arise whenever radiation sources are no longer under proper control. Such sources include -

- **X-ray equipment** - used for medical diagnosis and treatment, industrial and commercial inspections, quality control techniques, irradiations and research.

- **Accelerators** - used for medical treatments, industrial irradiations, production of radioisotopes and research (for some of these, electron accelerators only are used; for others, electron or particle accelerators are used).

- **Radioactive materials** - used for medical diagnosis and treatment, industrial radiography, quality control and tracing techniques, soil density and moisture tests and research (for some of these, the radioactive material may be in sealed containers but for others, it may be unsealed material).

- **Nuclear processing and reactor plants** - used for processing uranium and plutonium for fuel purposes and nuclear weapons, power production and research.

In addition, radiation accidents may occur in mining and processing uranium and thorium ores, transporting radioactive materials, working with equipment where radiation is a by-product (e.g., television receivers) and with nuclear weapons (although in the case of terrorist activities, this is not an "accident").

Depending on the type of accident, one or many individuals may be involved. Usually, if the accident occurs within the workplace, the number of individuals is likely to be small but if members of the public are involved, the number may be quite large; in the latter case, however, most of those involved would probably only have low exposures to radiation. If the source of radiation is one which people are not aware of at the time of the accident, the chances are that the number of people that could be affected may be significantly higher than originally thought.

Most radiation accidents are of a minor consequence as far as health effects are concerned. Examples of these include spillage of radioactive solutions in small areas, spots of contamination on the skin and so on; these can be easily and quickly cleaned up. They may be of a nature such that their reporting to authorities is not required; however, they should be acted on in order to overcome any difficulties or carelessness arising in work procedures.

Radiation accidents can be divided into two types -

- those in which a person is exposed to external sources of radiation

- those in which a person has radioactive contamination either on the skin (and clothing), inside the body or both.

It is possible that both types could occur in the one accident, but this would be exceptional.

1.1 Accidents with External Sources

The first type of accident has most commonly occurred with people using X-ray analysis equipment, repairing and using irradiation facilities, administering X-ray and electron therapy doses to patients and picking up sealed radioactive sources, notably high activity industrial radiography sources and placing them in their pockets for hours or perhaps days. Some of these accidents have arisen from the unlawful by-passing of interlock systems, carelessness in work activities (sometimes this has involved not checking that equipment is operating), equipment malfunction and not being aware of the presence of a radiation beam or a radioactive source (this is particularly the case when a member of the public becomes involved in an accident).

With external exposures, very high doses can be delivered to the whole body or to large areas of the body, but in most cases the exposure will be uneven; these high doses can give rise to what is known as the acute radiation syndrome. Much more often, high doses may be delivered to small parts of the body, and these give rise to local radiation injuries. However, most accidents involving external exposure only result in low doses to small parts of the body and these do not produce any observable effects. Effects from large doses can become manifest in a short period of time - hours, days, or a few weeks.

1.2 Accidents with Radioactive Contamination

The second type of accident most often occurs in the workplace. The levels of radioactive contamination are usually low and can be easily reduced. The common causes for individual contamination are -

- wearing inappropriate or damaged protective clothing or not wearing any protective clothing at all;
- incorrect removal of protective clothing;
- carelessness in work activities and non-compliance with prescribed work procedures;
- carelessness in personal hygiene or in other things such as scratching the face with a contaminated glove; and
- working in an environment where radioactive material is not within a container and may be touched or inhaled.
- Other situations where radioactive contamination of people either in the workplace or in the public arena can occur are -
- accidents which may be due to equipment failure and there being no mechanism to contain released radioactive material
- accidents arising in the transport of radioactive materials
- medical misadministration of radio-pharmaceuticals or rupture of a sealed source during preparation, treatment or repair

- deliberate actions which accidentally or otherwise result in the uncontrolled release of radioactive material to the environment

- being unknowingly in an area where levels of radioactive material are higher than normal; and

- handling unsealed or damaged sealed radioactive sources without being aware that they are radioactive.

When accidents occur in the workplace, the situations can often be brought under control within a short period of time and the degree of contamination is usually relatively small. When members of the public are involved, the total amount of contamination can be considerable and difficult to reduce as it may be dispersed over a widespread area.

Radioactive contamination may be deposited on the skin and clothing and may also be inhaled or ingested. Any deposited in wounds or in body orifices may be absorbed or transferred into the body fairly quickly. Except in the very rare case of extraordinarily high levels of contamination being deposited on the skin or taken into the body, there are no symptoms arising from contamination. The accident in Goiania, Brazil (see Bibliography) is an example of very high levels of contamination resulting in symptoms of the acute radiation syndrome becoming manifest. In another accident, very high levels of a beta-emitting contaminant resulted in a burning sensation, epilation and superficial scarring of the skin.

In an accident, injuries or trauma due to agents other than radiation may also occur. Radiation does not and cannot cause immediate injuries that are life threatening, such as cardiac arrests, blocked airways and haemorrhaging. These may result from the accident or be caused by the state of health of the individual. Recovery from certain injuries or illnesses may be retarded because of the effects of radiation exposure on body cells and tissues and this may, in itself, result in death of the individual whereas the radiation exposure by itself would not have the same consequence unless it was extreme. Death may also occur if an injury or illness occurs shortly after the radiation exposure.

1.3 Incidence of Radiation Accidents

In the USA, the Radiation Emergency Assistance Centre and Training Site (REAC/TS) at Oak Ridge maintains a Radiation Accident Registry. Details of all significant radiation accidents it has been informed of since 1944 are entered in this Registry. A summary of the accidents in the Registry up to June 1990 is given in Table 1.1. Includes fatalities which may have been due to physical trauma in the accident.

Table 1. 1 Major Accidents listed on REAC/TS Registry

Major accidents	No of accidents	No of persons involved	No of persons with significant exposures	No of fatalities
All except those listed below	323	5,955	1,403	65
Chernobyl, USSR	1	116,500	500	32
Goiania, Brazil	1	249	36	4
El Salvador, Mexico	1	7	3	1
Kyshtym, USSR	1	10,180	1,054	0
Total	**327**	**132,891**	**2,996**	**102**

In Australia, the National Health and Medical Research Council recommended in 1971 the establishment of an Australian Radiation Incidents Registry, to be maintained by the Australian Radiation Laboratory.

This Registry does not define a significant accident as in the REAC/TS Registry. It records accidents where exposures occur that are not "within the limits known to be normal for the particular source of radiation and for the particular use being made of it". Information on exposures that arise or could arise from defects in equipment is also recorded so that it can be used in the preparation of codes of practice, equipment standards or by regulators and manufacturers to ensure that equipment is of a satisfactory standard. There are very few accidents recorded in the Registry where individuals have been involved in radiation accidents and have received exposure or contamination at levels large enough to cause health concerns.

In February 1999 ARPANSA was formed from the amalgamation of the Australian Radiation Laboratory (ARL) and the Nuclear Safety Bureau (NSB). ARPANSA has taken over responsibility, for maintaining the incident registry. The quality and content of the registry is dependent on the reporting of incidents to the state regulatory authority and to ARPANSA through the newly formed Radiation Health Committee.

REAC/TS Radiation Accident Registry

In the USA, the Radiation Emergency Assistance Centre and Training Site (REAC/TS) at Oak Ridge maintains a Radiation Accident Registry. Details of all significant radiation accidents it has been informed of since 1944 are entered in this Registry. It includes 327 major accidents, up to June 1990, in which 102 individuals died; this includes 11 non-radiation deaths, i.e., individuals who were involved in radiation accidents, but who died from other causes. It is possible that, had they not died from other causes, they may have died from the effects of radiation but this is not certain. The Registry includes the accident at the Chernobyl nuclear power plant in which 28 people died from radiation exposure and 4 from other causes. REAC/TS does not claim that all accidents in the world are recorded in the Registry, but estimates that the total might be perhaps 50% to 100% higher. The number of deaths averages about two per year on a worldwide basis. [This contrasts with 50,000 deaths annually from traffic accidents and 8,000 from fire in the U.S. alone]. About one third of these deaths were caused by the accident at Chernobyl. The accidents have involved a large number of people, many of whom would have received significant exposures. A summary of the accidents in the Registry up to June 1990 is given in Table 1.1.

For purposes of the Registry, REAC/TS defines a significant accident as follows -

Dose to the whole body, blood or gonads	0.25	Gy
Dose to the skin or extremities	6	Gy
Dose to other organs from external radiation sources	0.75	Gy
Activity of radioactive material in organs	0.5 x	MPBB
Medical misadministration	0.5 x	MPBB

where MPBB is the maximum permissible body burden, as used by the U.S. National Council on Radiation Protection and Measurements. These doses and activities carry a risk of long-term effects ranging from about 1 in 1000 for some organs to about 10 in 1000 for whole body exposure, based on the risk factors used by the International Commission on Radiological Protection (ICRP) in its 1990 Recommendations.

Accidents which are termed significant can arise in a variety of situations. An analysis of the REAC/TS Registry shows that of the 327 accidents to June 1990, 18 were in nuclear installations (i.e., nuclear power plants, reactor sites and enrichment plants), 84 with unsealed radioactive sources (of which 38 involved medical diagnosis and therapy misadministrations), 147 with sealed radioactive sources (many of which were high activity industrial radiography sources), 62 with X-ray devices (many of which were X-ray analysis units), 15 with accelerators and 1 with by-product radiation. Such an analysis is useful in highlighting the most likely situations where accidents occur. Many accidents have occurred as a result of deliberate acts of bypassing safety devices or of not following safety procedures. In a number of cases, innocent members of the public have been the victims of those acts. Some of these accidents have had detailed reports published on them (see Bibliography).

2.0 RESPONSE TO RADIATION ACCIDENTS

The response to a radiation accident and the care necessary for individuals involved in such accidents depends to a large extent on the type of accident that has occurred, i.e., whether the individuals have been exposed to external sources of radiation or contaminated with radioactive material. The same general principles for caring for these individuals apply at the scene of the accident as at a hospital, but the detail and extent of care involved differ in the two places.

The responders to a radiation accident must have confidence that, provided they follow appropriate procedures, there will be no consequences to them, either directly or indirectly, as a result of caring for individuals involved in the accident. This confidence must also be apparent to the individuals themselves. The responders must be aware that if an individual has only been exposed to external sources of radiation, there is no radiation threat whatsoever to them and that precautions are not needed to prevent spread of radioactive contamination.

If an individual is only contaminated internally, as a result of inhalation or ingestion of radioactive material, then he/she does not present a direct hazard to others, unless the intake was extremely large. In that case, responders may be subject to external exposure as a result of the contamination inside the individual, but such exposure should be very low. If an individual has radioactive contamination on the skin (and clothing) and/or in excreta or body fluids, special precautions need to be implemented to prevent the spread of contamination.

If any contamination is transferred to responders, premises or equipment, this can be reduced to acceptable levels, and in most cases completely removed so that there is no significant hazard. The only survivors of a radiation accident who have been so badly contaminated as to be a threat to those involved in treating them were some of those involved in the accident at Chernobyl. No other accident victims, including those at Goiania, Brazil, where gross contamination of the victims occurred, have presented any threat to responders, due to the precautions and procedures they followed in managing those victims.

The care of individuals who are contaminated with radioactive material usually requires the same type of preparation and precautions as those used for individuals with other contaminants such as hazardous chemicals. Just as the risks associated with dealing with these other contaminants can be reduced to very low levels, so can the risks associated with radioactive contamination. The latter has the advantage that it can be readily detected by instruments when on the skin, whereas other contaminants may not be so easily detected.

Some chemical contaminants may be detected by smell or colour (some of which are not always discernible to everyone), or by skin reactions or biological monitoring. In general, these other contaminants cannot be detected spontaneously and certainty of their reduction to satisfactory levels may take some days. With radioactive decontamination procedures, the value or otherwise of each step can be assessed as the procedure continues.

2.1. Response at the Scene of an Accident

2.1.1 Preparedness within an Establishment

There is always a possibility of radiation accidents occurring at establishments where radiation sources or radioactive materials are used, no matter how careful people are and how many controls are in place. Plans should therefore be prepared so that appropriate action can be taken, should an accident occur. The plans should be based on all foreseeable situations. If an unforeseen situation arises, the various procedures given in the plans would still be invoked, but some of the actions may need to be modified to suit the situation. After an accident, all the procedures and actions taken should be promptly reviewed to evaluate their effectiveness and to determine where improvements are needed.

In some accident situations, radiation exposure or radioactive contamination may be incidental to other effects of the accident. This does not lessen the concern over radiation effects, but may mean that attention has to be directed to these other effects first. In planning, the possibility of a variety of hazards may need to be taken into account. These include fires, fumes, toxic chemicals, radiation exposure or radioactive contamination, electrical hazards, structural damage to property, etc. Fires and fumes can cause radioactive materials to become airborne, thereby increasing the spread of radioactive contamination. Many of the procedures adopted for dealing with radioactive contamination would be similar in nature to those for dealing with some other hazardous agents, although some, but not all, of the actions taken may differ.

Planning should take into account -

- the work activities, radiation sources and radioactive materials used in the establishment;

- the personnel involved in managing the situation, i.e., the physician at the establishment (if there is one), other persons who have had medical training such as nurses and first-aid officers, health physicist and rescue team members;

- provision of equipment, i.e., monitors for detecting radiation or contamination; equipment, fluids and medicines for decontaminating victims etc; bags for containing biological and other samples, contaminated items and radioactive waste; and other items such as warning signs, area demarcation barriers, protective clothing, etc;

- the need for admission to a hospital - this should be a hospital designated to manage radiation accident victims, if such a hospital exists in the area; and

- advice to the admitting hospital of the victim's arrival to allow for preparation, radiation control authorities and other relevant organisations, the victim's family and the media (if need be).

- Not all accidents are such that the detailed plan needs to be drawn on. In many cases, accidents may only involve a spill of radioactive liquid, with only part of clothing or intact skin being contaminated. In these cases, the contamination can be easily removed under supervision and the procedures outlined below are not required. However, accidents cannot always be treated as being trivial, as radioactive contamination may be absorbed into the body through the

- skin or, more likely, through small cuts or wounds in the skin which are unnoticed. Contaminated areas of the body should be checked scrupulously.

- It is important that all workers in an establishment know the fundamental steps to be taken when accidents involving radiation occur in the workplace. They should receive appropriate training for this purpose. In many cases, this may simply mean knowing who are the most appropriate people to contact. In general, the steps are often the same as for hazardous chemicals and they should also be aware of these if used in the establishment. In the first place, they should make a quick assessment of and report –

    - any hazards in the area, such as fires, fumes, toxic chemicals, continued possibility of radioactive contamination and structural damage to property; and
    - the need for any life-saving procedures to be implemented for cardiac arrests, blocked airways, haemorrhaging, etc. Any possibility of spine or neck damage, in particular, or of broken bones should be reported.

2.1.2 Accidents Outside an Establishment

In the event of an accident occurring outside an establishment, those discovering the accident should contact the Police. If possible, they should also report any of those things outlined in the above paragraph. The Police, in turn, would contact other bodies, such as the ambulance and fire brigade, if necessary, and the radiation control authorities so that radiological assessments of the area and any victims can be made. Reference to the role of some authorities is given in Appendix A1 Any information regarding the accident and the radiation source or radioactive material involved should be obtained and made available to the hospital admitting the victim so that the most effective treatment can be implemented (see Notification Requirements below).

2.1.3 Immediate Care of Victims

If external exposure is involved in an accident, there is no treatment that can be carried out at the scene of the accident. However, the victim should be sent to hospital so that early observation and any necessary monitoring of the various body systems can be made. A preliminary assessment of the radiation dose received by the exposed parts of the body should be made as this will give an early indication of the possible symptoms and will be helpful in formulating the treatment to be given. Detailed dose assessments should be made later .

If a person is contaminated with radioactive material, it may only involve small contamination spots on the skin and this can be easily removed at the scene of the accident. If it cannot be easily removed, the victim should be sent to hospital for procedures for cleaning the skin. However, accidents may occur which are much more dangerous - ranging from cuts with contaminated glassware through to a large inhalation or ingestion of radioactive material or serious injuries that require the implementation of life-saving procedures. These injuries would not be caused by radiation or radioactive contamination but by other agents or physical situations arising in the accident. They may even depend on the victim's state of health.

Other hazards present, such as fire, fumes, toxic chemicals or physical damage to property can complicate rescue procedures and may compound treatment procedures normally followed when radioactive contamination only is involved. Victims of other than minor accidents should always be sent to hospital for treatment.

Those discovering the accident should seek assistance immediately and should not move the victim unless the accident area is extremely hazardous; however, if the victim has spinal fracture or life-threatening injuries, movement may aggravate his/her condition more than would the hazardous situation. Accident victims should not be left on their own, unless it is necessary to obtain assistance, as they will need support throughout the ordeal.

Life-saving procedures, control of haemorrhage, fracture stabilisation and decontamination actions should be carried out, but only by those specially trained, as attempts to do these things by others may only complicate matters. Once the victim's condition has been stabilised, wounds should be dressed or redressed with sterile dressings; the old dressings should be placed in individual, labelled plastic bags for later analysis. It may also be desirable to move the victim to an area of lower contamination provided there are no problems such as spinal damage. Arrangements should then be made to transfer the victim to hospital.

If a physician works in an establishment or is in close proximity and likely to be readily available, he/she should become familiar with treatments to be given for the different radionuclides that may be involved in an accident. Where possible, he/she should implement some initial treatment before the victim is sent to hospital. This includes simple expedients such as oral and nasopharyngeal irrigations and the use of blocking agents for certain radionuclides that might have been ingested or inhaled so as to reduce the transfer of contaminants within the body. It may also be useful, particularly if transuranic elements are used in an establishment, to have available a first-aid kit of compact size which contains a small selection of simple, non-toxic medicines packed in individual dose units. These units could be administered immediately after an accident by an officer who has been suitably trained.

The use of this kit does not, under any circumstances, excuse the victim from reporting to the physician, who will administer any further treatment if necessary before the victim is sent to hospital and will make up a fresh kit.

2.1.4 Rescue Team Procedures

In some situations, the presence of radioactive contamination may be of much lower concern to the health of individuals than would be the presence of other hazards and these other hazards may need to be put under control first. Rescuers should be informed of any hazards present, all details of the accident and the victim's condition. This information may predicate the type of treatment and rescue procedures to be carried out at the scene of the accident as well as any subsequent treatment at the hospital. The environment should be rendered not immediately hazardous before rescue operations start so that the rescuers do not put their own lives at risk unnecessarily.

Members of the rescue team should put on protective clothing (including gloves, face-mask and cap) which is normally used by workers in the area when working with radioactive material. It is unlikely they will need anything more protective, unless other hazards are present. Where necessary, large plastic aprons covering gowns to make them waterproof, plastic bags taped over shoes, etc. can be used if the protective clothing normally used is seen to be inadequate for accident situations. For the implementation of urgent life-saving procedures, it may be necessary to forego some of this protection; any subsequent contamination to the rescuer will be low and can be effectively removed later.

2.1.5 Control and Preliminary Monitoring of Radioactive Contamination

Immediately after an accident, a controlled area should be established around the accident area to minimise the spread of radioactive contamination. The periphery of this area should be located just outside the region where contamination can be detected above background levels. Only equipment and rescue teams should enter the area and security arrangements should be made to prevent unauthorised entry. Checkpoints should be established where the victim, rescue team members and equipment can be monitored as they leave the controlled area. Protective clothing worn by the rescue team should be removed at these points, prior to their being monitored. Clean-up, decontamination and waste disposal activities carried out after removal of the victim should follow good, established radiation protection procedures. Sometimes, a buffer zone round the controlled area can be helpful, particularly if there are many people present in the area.

Provided time and the victim's condition permit, monitoring of the victim for contamination should be made with a suitable radiation monitor after stabilisation. It may even be possible to do some monitoring during any stabilisation of the victim provided there is no interference with that activity from monitoring procedures. This monitoring will indicate areas on the body and clothing which are relatively high. If any small areas of intact skin are contaminated, these could possibly be cleaned at this stage if the victim is not injured and if the accident occurs in a facility where there is a health physicist. Nasal and oral cavity swabs should also be taken to obtain an indication if any intake of radioactive material was small or large. After initial measurement with the monitor, the swabs should be placed in individual, labelled plastic bags for later analysis. However, if the victim is injured or ill, he/she should be transported to hospital for assessment and treatment.

2.1.6 Removal of Contaminated Clothing

In accidents where external radioactive contamination is likely to occur, it is possible that as much as 70-80% of this could be on clothing. In order to minimise the spread of contamination, the victim's outer clothing should be removed at the earliest practicable stage after an accident. This should preferably be done at the scene of the accident, but if there are problems such as spinal injuries or the victim's condition is deteriorating, removal of clothing should be carried out by paramedics or deferred until the victim reaches hospital. Removal of outer clothing also makes it a lot easier to see the extent of any external injuries at an early stage.

Monitoring would show the extent of contamination on clothing and this may reduce the need for removal of all outer clothing. If a monitor is not available, however, it should be assumed that all the outer clothing is contaminated; in this case, it should all be removed.

The inside of clothing is not likely to have very much contamination on it unless the radioactive material was liquid and seeped through the clothing. Accordingly, to remove clothing, it should be cut from head to toe and down the sleeves, folded back under itself as it is cut, and then rolled up. By doing this carefully, the inside of the clothing will come to the outside and the possibility of spreading contamination very much reduced. Zippers can be undone rather than cut. If possible, ripping of clothing should be avoided to prevent dispersion of contaminated fragments, but ripping may be necessary at times when implementing life-saving procedures. Clothing and personal items should be placed in labelled plastic bags for subsequent decontamination and return to the patient. The person removing the victim's contaminated clothing must wear protective clothing and take care not to touch the outside of the victim's clothing.

2.1.7 Movement and Transport of Contaminated Victims

Following removal of contaminated clothing, two sheets (or blankets) should be placed one on top of the other and the victim lifted or rolled on to the top sheet (subject to there being no injuries to prevent this movement). The top sheet (which should be uncontaminated) should then be lifted with the victim still on it on to the ambulance stretcher. Following that, it should be folded over the victim so that he/she is completely surrounded by the sheet and any remaining contamination is contained within the "package". The bottom sheet would probably be contaminated underneath and should be cleaned or disposed of appropriately.

Movement of a victim with serious injuries, such as spinal damage or a leg in a splint should be made by a qualified first-aid or ambulance officer. For this, the victim should be immobilised; there should be only one transfer movement of this victim, i.e., from the point of discovery to the ambulance backboard. This backboard would, in turn, be transferred to the hospital theatre table with the victim still on it. In these circumstances, it may not be possible to remove all the contaminated outer clothing at the scene of the accident but as much as possible should be removed. To remove clothing from the back of the victim, he/she should be rolled on to the side with somebody controlling the head and shoulders. After removing the clothing on the back, he/she should be rolled back on to a backboard which has been positioned on a double layer of clean sheets (or blankets). Then the top 'sheet should be wrapped round the victim and the "package" lifted on to the ambulance stretcher. The bottom sheet should be cleaned or disposed of appropriately.

2.1.8 Notification Requirements

As soon as possible after an accident, the accident and emergency department of the hospital should be advised that one or more victims will be sent for treatment; their anticipated arrival time at the hospital and whether by ambulance or private car should be given.

As the preparation for and treatment of an accident victim at a hospital depends very much on what happened in an accident, a detailed description of the accident and the following information in relation to the accident should be made available at the time of notifying the hospital –

1. for external exposure, the type of radioactive source involved or the X-ray energy involved - this will be used to determine whether effects are likely to be superficial or to deeper organs and tissues;

2. for external exposure, the part(s) of the body exposed and the exposure period-these will be used in conjunction with (1) above and any physical measurements of exposure to assess the doses delivered;

3. for radioactive contamination, the radionuclide and the chemical form and particulate size (if known) of the radioactive material involved knowledge of the radionuclide will be used to choose appropriate monitoring equipment;

4. for radioactive contamination, whether the material is likely to have been inhaled, ingested or deposited on the skin - this will be used in conjunction with (3) above to determine the tissues and organs at risk and the decontamination procedures to be used;

5. the number of victims, their conditions and details of any monitoring, biological samples collected or treatment carried out;

6. the time of the accident - this can be used in conjunction with (1) and (2) or (3) and (4) above to indicate the likely time of onset of any symptoms, the urgency of implementing treatment or decontamination procedures and the appropriate time to commence any monitoring of biological samples; and

7. other hazardous materials at the scene of the accident.

If several radiation physicists are at the scene of the accident, one could proceed to the hospital in advance of the victim and advise, if necessary, on preparation needed for the victim. This physicist would be able to check for contamination at the entry to the hospital upon arrival of the victim there, as well as in the ambulance and on the ambulance officers before they leave the hospital.

If the accident is one where many people are contaminated, it may be desirable for the hospital to send a triage officer to the scene to sort out the more serious cases from the others. Some victims with minor contamination and no other injuries could be showered and decontaminated at a community centre, checked for contamination and, if there are no problems, be counselled and sent home.

In certain circumstances, there is a requirement for accidents to be reported to the relevant radiation control authorities. Initial reporting should be carried out shortly after the accident, as officers in these authorities would offer advice on decontamination and waste disposal procedures. Follow-up reporting should be made, if required, to the authorities with all details relating to the accident. The cause(s) of the accident should be thoroughly investigated and action taken to minimise the possibility of repeat accidents.

2.2 Response at the Hospital

2.2.1 Advice of Arrival

The accident and emergency department of the hospital should always confirm the information received about the accident and the victim(s) with those at the accident scene and from field medical providers. It should update the information on the victim's condition (both medical and psychological) and on any treatment, radiation monitoring and decontamination already undertaken, as well as on any special handling procedures or precautions needed at the scene or during transport of the victim. The hospital should advise which entry is to be used for admission of the accident victim.

Once advice is received that an accident victim is being sent to the hospital, the emergency response team should be alerted so that appropriate preparation can be made. If there is no warning of arrival of an accident victim, details relating to the accident, any injuries, monitoring and treatment should be obtained at triage. Sometimes, however, the victim may not be aware that he/she has been exposed to radiation or is contaminated. Treatment may be sought because of the appearance of unexplained symptoms, perhaps hours, but more likely days or weeks after the accident. This invariably means that the radiation dose was large or there was a high degree of contamination. Very careful questioning may be necessary for it to become obvious that there was involvement in a radiation accident. In these situations, details of the accident may be somewhat vague or unknown, particularly if the individual is a member of the public who knows nothing about radiation or radioactive material.

2.2.2 Assessment of Treatment Priorities

Immediately after an accident, as well as upon arrival at the hospital, assessments should be made to see if there is a need to implement any life-saving procedures. With radiation exposure or radioactive contamination, there is no medical emergency, such as with cardiac arrest, blocked airways and haemorrhaging. Therefore, any necessary life-saving procedures must be implemented ahead of any other actions related to the radiation aspects of the patient's condition even if preparations to minimise spread of contamination have not been completed. It is imperative that his/her condition be stabilised before implementing any other treatment.

When radioactive contamination is involved in an accident, radiation monitoring should be carried out as soon as possible after the accident and again after arrival at the hospital so that an early assessment of contamination levels on the patient becomes available. Such monitoring includes skin, clothing and body orifices. Records of contamination levels, together with location of wounds etc. should be made, preferably on a body chart, at the time of this monitoring. This monitoring is unlikely to detect internal contamination unless a gamma-emitter is involved. Although this monitoring must not delay life-saving procedures, it may be possible to do some of it during these procedures, provided it does not interfere with them. More detailed monitoring can be carried out later.

At triage, details of the accident, any treatment given, etc., as well as the usual type of information should be checked. In addition, information should be obtained of existing injuries or illnesses, use of medications, allergies, time of last meal, etc. All injuries or illnesses present prior to the accident or caused by the accident can complicate the patient's medical condition and course of treatment and must be taken into account. In addition, any injuries or illnesses occurring after the accident up to the time that recovery from the accident is deemed to have occurred may also affect the treatment and this may have to be modified. Accordingly, the patient must be told to report immediately any injuries or illnesses incurred after the accident, no matter how trivial they are.

In addition to obtaining information referred to in the last paragraph, a physical examination of the patient should be made to assess the types of injuries present and their urgency for treatment. If possible, their treatment should be deferred until any decontamination procedures have been completed. Note should be made of any wounds, skin punctures, etc. which could be contaminated, as they will need urgent attention as could some of the body orifices if they are contaminated. It may also be necessary to collect urine samples (which may not show any signs of radioactive contamination at that stage) and draw blood samples for complete blood counts, differential and absolute lymphocyte counts and possibly for later cytogenic analysis. These samples would give baseline data against which later samples could be compared (Chapter 7). Triage would take into account any symptoms at the time of admission to the hospital, any reported prior to admission and the haematological picture as soon as it becomes available.

There is a medical urgency to initiate procedures to remove as much internal contamination as possible before it reaches target organs. The earlier such removal is tackled, the easier is the process and the better will be the outcome. The benefits of implementing procedures for the removal of internal contamination can be something of the order of a two to ten times reduction in doses to organs, with a corresponding reduction in the risk of long-term effects such as the induction of cancer. In addition, the early removal of contamination helps considerably in allaying fears held by the patient. These procedures should, therefore, take precedence over other procedures except life-saving procedures or where it is seen that the patient is in great pain or that his/her condition is deteriorating rapidly through other causes.

A decision will have to be made at triage as to which component of contamination should be tackled first; this would be based on the levels found at different parts of the body. Any wounds or body orifices would probably be first choice, unless information shows that the amount inhaled or ingested is very much larger than that which could be absorbed through wounds and body orifices. Removal of gross contamination from hands, face and head is desirable to reduce the potential for spread of contamination. Decontamination of intact skin would probably be the lowest priority.

2.2.3 Routing of Patients through the Accident and Emergency Department

After admission to hospital and stabilisation of the patient's condition and triage, he/she should go through the normal accident and emergency department procedures if external exposure only has been involved. if radioactive contamination is involved, then he/she should be kept in a controlled area until such time as the contamination levels have been confirmed. If internal contamination only is involved, which would be rare, and no intervention such as lavage is proposed, then the patient can go through the normal accident and emergency department procedures. However, procedures to control contamination from urine, faeces, vomitus, or other body fluids should be instituted. If external contamination or internal contamination with lavage, etc. is involved, decontamination procedures should be instituted with controls to prevent the spread of contamination. Once contamination has been reduced to acceptable levels, the patient should go through the normal accident and emergency department procedures. A suggested flow through the department, together with a treatment plan is given in Fig.2.1.

2.2.4 Counselling of Patients

After treatment and possibly even during treatment there will be a need for counselling the patient. This arises from the general fear of radiation in the community and the fact that it is almost impossible to remove one hundred per cent of the radioactive contaminants from the body. Some counselling of relatives may be necessary as well. Follow-up of most patients is desirable to establish any late or delayed radiation effects, providing on-going counselling support and reassurance as well as institute follow up treatment if needed.

Fig 2.1 Suggested schematic flow of a patient through the accident and emergency department.
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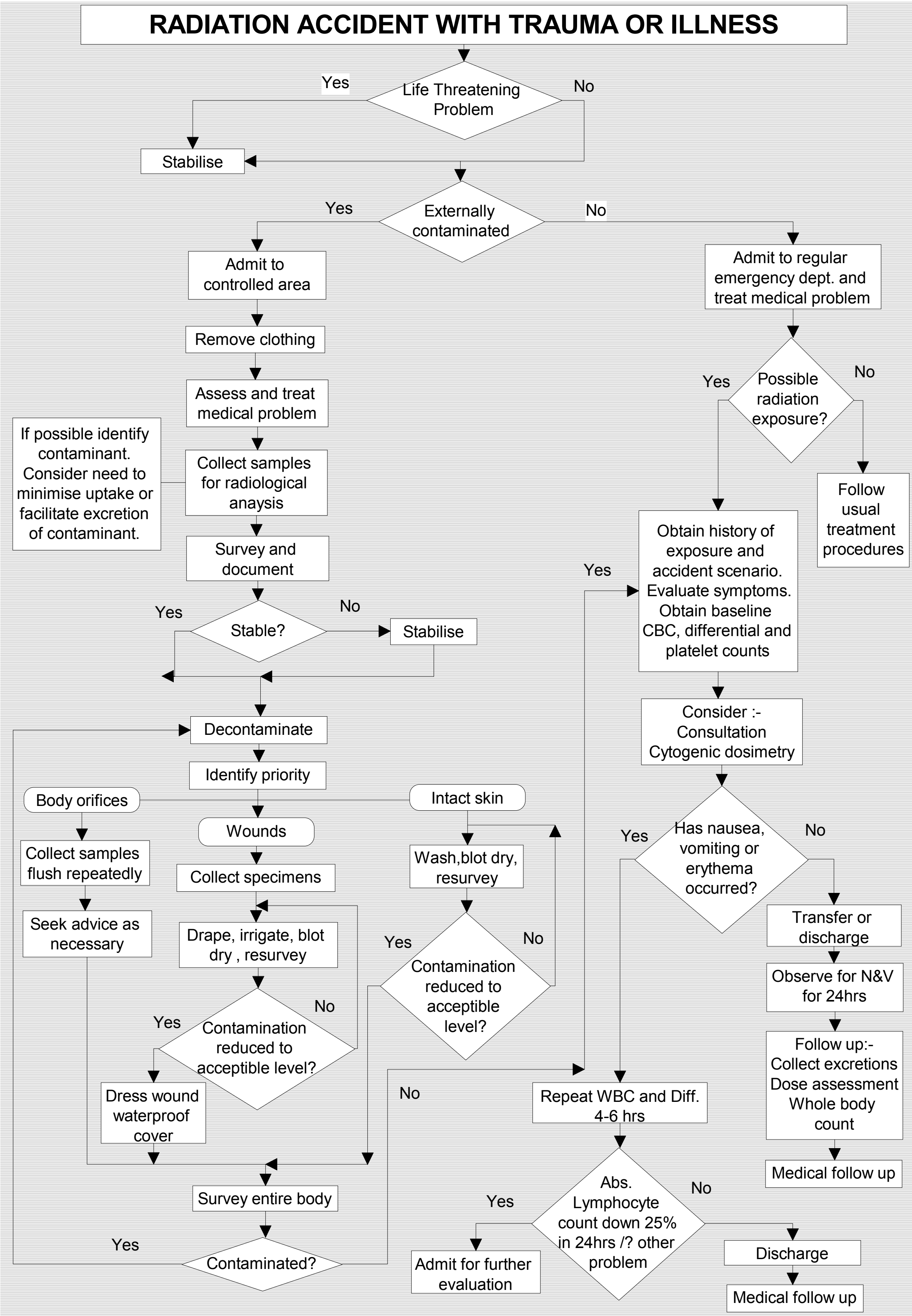

3.0 ASSESSMENT OF DOSES RECEIVED FROM EXTERNAL EXPOSURE

If an individual is exposed to external sources of radiation, it is important to know the doses received by different parts of the body. Although treatment given shortly after such an exposure must be based on early symptoms, it is helpful to know the dose on the skin and to underlying tissues, organs and body systems as any damage to these may affect subsequent ability to recover and must be taken into account in further treatments. Preliminary estimates can usually be made fairly quickly after an accident, but detailed estimates may take some time - days or weeks, depending on the circumstances.

Although the severity and time of onset of early symptoms can give an indication of the doses involved, physical measurements and/or calculations based on the accident situation should be made. This often involves a re-enactment of the accident, based on information given by the victim and others nearby at the time. These measurements would, in most cases, be carried out at the scene of the accident but at some later time.

In making measurements to determine the doses received, an instrument such as a gaseous ionisation chamber or scintillation detector is placed at the various positions that were occupied by the different skin areas of the victim during the accident. The doses to the skin can then be determined by converting any exposure measurements to absorbed dose (if need be) and allowing for the time the victim spent in each position. From these values, the doses to underlying tissues, body systems and organs can be calculated.

For some accident situations, the radiation field may be high and it may not be possible to carry out a re-enactment without those doing so receiving an unacceptably high dose. To overcome this, measurements can be made at positions different to those occupied by the accident victim and the doses at occupied positions then determined by calculation. Alternatively, use can be made of a manikin with small dosimeters, such as thermoluminescent dosimeters (TLDs), attached at strategic points to it; the manikin is placed at the position(s) occupied by the victim during the accident and the TLDs read out after the re-enactment to give the doses received. In other cases, doses can be derived by calculation; this is particularly the case when high activity radioactive sources are involved.

Assessment of doses, as outlined above, can result in large errors as they usually depend on the reconstruction of the accident situation and making measurements based on the victim's memory of what happened. In this regard, the sequence of events may be well remembered, but the time spent in different activities and in different positions can be grossly under or overestimated. Accordingly, other dosimetry systems can be useful.

Analysis of the blood serves as a useful method of monitoring and can be used to confirm or, perhaps, obtain a better indication of the dose received. If complete blood counts, differential counts and absolute lymphocyte counts are made at different times after an external exposure (or after intake of radioactive material), then estimates of the dose can be made and the degree of medical treatment needed can be assessed. For example, decreases in the absolute lymphocyte count, if they occur, will be apparent within 24 hours. If the count is greater than 1200 mm^{-3} at this time, the clinical support required will be minimal; if below 500 mm^{-3}, a very severe course can be anticipated. These counts also assist in monitoring the condition of the patient whilst undergoing a course of treatment. Reference is made to changes in the various blood counts in *Chapter 4.*

Blood samples can also be used in cytogenetic studies, i.e., studies of the number and structure of chromosomes. Radiation dose is reflected basically in the number of excess acentrics and dicentrics produced after an exposure. Three tissues can be used for this :- peripheral blood lymphocytes, bone marrow cells and fibroblasts. Fibroblasts have not proved to be as good a dosimeter as originally anticipated; bone-marrow cells are very good to use, but not pleasant to extract from a patient. Peripheral blood lymphocytes are easy to obtain and are less traumatic to the patient.

The advantages of lymphocyte culture techniques are

- they require a very small volume of venous blood;

- metaphases are available for analysis within 48 hours of the culture being initiated;

- they can be cultured from transported blood samples within 48 hours of having been drawn, provided the samples have been properly heparinised and kept in a cool, but not frozen, environment; and

- T lymphocytes are relatively long-lived and reliable dose estimates can be made up to 5 weeks after an acute exposure.

The use of chromosome aberrations identified in the metaphase nuclei of cultured peripheral lymphocytes may be helpful in evaluating individuals suspected of being exposed to radiation doses as low as about 100-200 mGy. This form of monitoring is very useful when a personal monitor, for example, has not been worn or where partial exposure is involved in an area not covered by the monitor or when there has been a large intake of radioactive material.

4.0 TREATMENT OF INJURIES FROM EXTERNAL EXPOSURE

This Chapter is concerned with injuries that are of a deterministic nature arising from external exposures in a radiation accident, i.e., with those injuries that become manifest within a short period of time (hours, days or weeks) after the accident. It is not concerned with the stochastic effects - i.e., the induction of genetic effects and of cancer, which may never become manifest; if they do, it will be many years after the accident and only rarely can they be directly related to the radiation exposure occurring in the accident.

The injuries arising from external exposure depend on -

- the dose received;
- the type of radiation;
- the position of the source relative to the body;
- the period of time over which the exposure occurred;
- the part(s) of the body exposed; and
- characteristics of the individual involved.

It is known that the greater the dose, the more severe will be the injury. For the injuries of concern here, there is a threshold dose below which injuries are not manifest; if there are no symptoms arising within the short term following exposure, there is nothing to be treated. The onset of any symptoms will also be earlier with higher doses.

The type of radiation involved will have considerable bearing on the damage to the body. For example, alpha particles will not penetrate the outer layer of the skin and there will be no damage. Beta particles will only penetrate tissue to a depth of a few millimetres (depending on their energy) and do not cause damage beyond this, whereas X-rays and γ-rays may pass right through the body and deliver a dose throughout the exposed part of the body. The LET of the radiation is also important in regard to the damage arising for a given dose. Beta particles, X- and γ-rays all have similar LET values, but neutrons and protons have much higher values and if these are involved, the damage will be much higher for the same dose; neutrons and protons have very rarely been involved in radiation accidents up to the present time (*Chapter 10 and Chapter 12*).

The position of the source relative to the body will affect the dose distribution through the exposed part of the body. For sources some distance from the body, X- and γ-ray intensities will decrease steadily throughout the exposed part of the body. For sources close to the body, very high doses can be delivered within the first centimetre or two, and then decrease rapidly through the remainder of the body; the dose to the distal parts of the body may, however, still be significant. In addition, the irradiated volume of the body may be small compared to that when sources are some distance from the body.

The time over which the exposure occurs can be very important. An acute exposure (i.e., one delivered in a short period of time) does not give the same ability for cell replacement or tissue recovery to occur as does a chronic exposure (i.e., one protracted over a long period of time). Hence, for a given dose, damage can be much greater with an acute exposure. A fractionated exposure (i.e., one consisting of several short exposures with periods of zero exposure in between) allows a period of recovery before further damage is done.

Damage to the body will also be dependent on the parts of the body exposed. In some accidents, the whole body or a major part of it, e.g., the head or abdomen may receive a large dose and body systems may receive doses which are high enough to cause systemic symptoms. In other accidents, only small parts of the body or of body systems are involved, so that the body as a whole can continue to function until full recovery is effected.

If a major part of the body is exposed to a large dose, that dose may be sufficient to cause death in some individuals but not in others. The dose that kills 50% of irradiated individuals, assuming there is no medical intervention, is referred to as the median lethal dose (LD_{50}). $LD_{50/60}$ is the median lethal dose that kills half the irradiated individuals within 60 days. This value depends on the direction of the radiation on the body - the value for dorsal irradiation is about two-thirds that for ventral irradiation. For young children, the value is probably lower than that of adults by a factor of two or more; the highest value probably occurs at about puberty, with a gradual decrease with age. There has not been shown, with any certainty, that there is any difference in the value between males and females.

There is considerable information given in the literature correlating symptoms with radiation doses received in accidents; there is a lot of variation in these, much of which is caused by different responses of individuals. However, differences in the information also arise from the manner in which the dose has been expressed. It may refer to the dose in air at the position occupied by the individual at the time of the accident, the dose on the incident skin or, for whole-body (or near whole-body) exposures, the mean dose to the body system involved (e.g., the mean bone marrow dose) or the dose to the midline of the body. The most commonly quoted dose is probably that in air at the position occupied by the individual. Although this is difficult enough to measure and assess in an accident situation, it is much easier to determine than are most other ways of expressing dose; it also allows easier comparison with other accident situations and the resulting effects.

It is better to assume dose in air at the occupied position unless the literature indicates otherwise. For low energy and penetrating radiation, the difference between the dose in air and that on the incident skin is not large enough to worry about, but for 50-150 keV (effective) photons, the skin dose can be as much as 30-50% higher than the dose in air (depending on the area irradiated). For penetrating radiation and large exposure areas, the dose at the mid-line of an average size adult would be of the order of two-thirds of that in air at the incident skin position.

The treatment of a patient will depend on the symptoms at the time of presentation. In turn, these will depend on the type of radiation involved and the dose received. The doses delivered to the various tissues should be determined, with reasonable certainty, as soon as possible after the accident. For this, physical measurements and assessments of the radiation levels should be made in conjunction with a reconstruction of the accident. This may take some time, days or even weeks, but there should be no delay in the treatment of a patient while waiting for this information. Treatment should be based on the symptoms observed and a description of the accident, which in themselves, should give some indication of the magnitude of the dose. As information on the doses becomes available and as further symptoms develop, the treatment course can be modified.

When accidents involve high external exposures, changes may occur in the number of the blood cells of the different types present and these should be investigated. These changes can be very helpful in indicating the course of treatment and in the assessment of results. If a sufficiently large area of the body has been irradiated, even non-uniformly, the results can be used in assessing the dose. By starting blood counts as soon as possible after an accident, any changes with time can be monitored. The first count would then give baseline values of the white blood cell, differential, platelet and absolute lymphocyte counts before any detectable changes occur.

Blood samples should also be drawn for HLA typing and later cytogenic analysis. Chromosome analysis will assist in estimating the dose and prognosis, and serves as a very useful adjunct to physical measurements and assessments. Chromosome aberrations may be detected in the lymphocytes below doses of 0. 25 Gy; they can be readily detected above this dose. Early samples of blood can be used for preliminary assessments, even though a complete analysis may take several days.

In some cases, the patient may also suffer from some other trauma, e.g., physical injury or shock. These may have occurred at the same time as the accident or could have occurred either before or after the accident and arise from some cause totally unconnected with the accident. Such trauma may need to be taken into account in any proposed treatment course. In these situations, concern is with a combined injury, i.e., with that arising from radiation exposure and that from other causes.

4.1 The Acute Radiation Syndrome

4.1.1 General Description

The acute radiation syndrome is the clinical manifestation of the responses of individual body systems exposed to acute or sub-acute doses of radiation. It is primarily due to the loss of cells in the body, particularly those cells that develop from stem cells and become functional cells in the body. The resulting effects of the exposure are due to an insufficient number of a particular kind of cell that forms a defined structure or performs a certain function in the body.

The term “acute radiation syndrome" is a collective term and is used to refer to one or more of the haematopoietic syndrome, the gastrointestinal syndrome, the cardiovascular syndrome and the neurovascular syndrome, although slightly different names for these syndromes are used from time to time. The syndrome arising depends on the part of the body irradiated, the dose and the time over which it is delivered. In general, however, it involves delivery of a large radiation dose in a short period of time to the whole, or near-whole, body from external sources of penetrating radiation such as high energy X-rays or γ-rays.

The possibility of a syndrome arising from internal deposition of radioactive material is extremely low, although this occurred in the incident at Goiania, Brazil (see Bibliography) and in a few cases arising from the misadministration of radio-pharmaceuticals to patients.

The acute radiation syndrome is an illness that follows a roughly predictable course over a period ranging from a few hours to several weeks after exposure. The initial symptoms may arise within a few minutes or hours of exposure, depending on the total dose and the regions of the body irradiated. Most of these early symptoms are due to the effects of radiation on membranes and the release of vasoactive amines. If the radiation dose is not sufficient to kill cells, these membrane effects are usually repaired and the effect disappears with time.

The course of the illness can be divided into four periods -

- the prodromal period, when the initial symptoms appear. These generally last up to 48 hours, although they have been known to last up to 7 days when the dose was received over several days;

- the latent period, when there are no symptoms. In this period, which may last from a few hours to weeks depending on dose, certain cells die and others are not produced to replace them;

- the manifest illness period, when the predominant symptoms occur as a result of cell damage and loss. For example, there may be symptoms of bleeding and/or infection; and

- either death or the recovery period. If recovery occurs, it could be of the order of 5 to 10 weeks after exposure.

The length of each period and the severity of the symptoms depend on the dose received - the higher the dose, the shorter each period and the more severe will be the symptoms. With very high doses, the periods may merge into each other and there will be no clear distinction between them.

4.1.2 Diagnosis and Assessment

In order to put into effect an appropriate course of treatment for a patient exposed to a high radiation dose, a good diagnosis and assessment of the condition is needed. This involves an early knowledge of the magnitude of the dose and the parts of the body irradiated. In most accidents, the whole body will not be uniformly exposed, due to shielding provided by nearby objects and some parts of the body shielding other parts. As a result, some of the cells in one of the body systems may survive and this gives a better chance for recovery of the patient. It is important, therefore, in considering a prognosis and a possible course of treatment to know the extent to which the body has been exposed.

In the absence of knowledge of the doses involved, a careful noting of the severity and timing of symptoms after the exposure will give some indication of the magnitude of the dose received and hence of the treatment to be implemented. Table 4.1 gives the expected temporal distribution of a number of symptoms following whole-body exposure and this can be used as a guide to the dose likely to have been received. It has been derived from studies made on a relatively small number of people. This illustrates how the severity and time of onset of symptoms vary between individuals.

The mechanism of the prodromal syndrome is not well understood but it appears that abnormalities in the autonomic nervous system are responsible for the early gastrointestinal symptoms. These are anorexia, nausea, vomiting, diarrhoea, intestinal cramps, salivation and dehydration. Vomiting is believed to occur because of effects at two sites - the chemoreceptor trigger zone and the vomiting centre in the brain. Exposure of the head and thorax to greater than 1 Gy can cause vomiting, but if the exposure is below the level of the stomach, the effect is very much less. Following exposure to other parts of the body, this effect is absent.

It has been shown in sub-human animal studies that, by shielding the epigastrium and giving a near-lethal dose to the remainder of the body, the animals did not show signs of nausea and vomiting. On the other hand, a high dose to only the epigastrium resulted in vomiting. Vomiting is believed to be caused by a humeral agent, radiolytic in nature, that is carried by the blood stream to the vomiting centre in the brain, thereby resulting in the prodromal period symptoms.

Other symptoms may also occur and these should also be noted. Episodic erythema, for example, may appear in the first few days. This may come in waves and could be easily missed. If the exposure is greater than about 15 Gy, erythema could reappear at a later time and characteristic changes to the skin colour (bronzing) may be evident at 2-3 weeks. Hypotension may also occur with very high doses, as may bloody diarrhoea, in which case the prognosis is very poor. Many of the symptoms occurring in the prodromal period can reappear in the manifest illness period, together with others.

Table 4.1 Temporal Distribution of Symptoms for Acute Exposure			
Midline Tissue Dose	**Symptom**	**% of individuals affected**	**Time after exposure**
0.5- 1.0Gy	Anorexia	15-30	3-18h
	Nausea	5-30	3-20
	Vomiting	15-20	4-16
1-2Gy	Anorexia	50-90	1-48h
	Nausea	30-70	4-30h
	Vomiting	20-50	6-24h
	Fatigue	25-60	3-72h
	Weakness	25-50	3048h
	Bleeding (mild)	10	1-5 wks
	Fever	10-60	2-150d
	Infection	10-50	1-5 wks
	Death	<5	5-6 wks
2-3.5Gy	Anorexia	90-100	1-48h
	Nausea	70-90	1-48h
	Vomiting	50-80	3-24h
	Fatigue (moderate)	60-90	2h-6wks
	Diarrhoea	10	4-8h
	Weakness (moderate)	50-80	2h-6wks
	Bleeding	10-50	1-5wks
	Fever	10-80	1-5wks
	Infection	10-80	2-5 wks
	Ulceration	30	3-5 wks
	Death	5-50	4-6 wks
3.5-5.5Gy	Anorexia	100	1-72h
	Nausea	90-100	1-72h
	Vomiting	80-100	3-72h
	Diarrhoea	10	3-8h
	Fatigue	90-100	1h-6 wks
	Weakness	90-100	1h-6 wks
	Headache	50	4-24h
	Bleeding	50-100	6d- 6 wks
	Fever and infection	80-100	6d-6 wks
	Death	50-99	3.5-6 wks
5.5-7.5Gy	Anorexia	100	1-72h
	Nausea	100	1-72h
	Vomiting	100	1-48h
	Diarrhoea	10	4-6h
	Fatigue & weakness	100	1h-2 wks
	Dizziness & disorientation	100	4-48h
	Headache	80	4-30h
	Bleeding, fever, infection & hypotension	100	10-14d
	Death	100	2-3 wks

The symptoms listed in Table 4.2 are grouped and listed in increasing order of severity and therefore in increasing dose. The corresponding doses have not been listed due to the large variation between individuals, but the likely doses can be gauged from Table 4.1. Not all symptoms in any one group will appear - this will depend on the regions of the body exposed.

Table 4.2 Signs and Symptoms Found in Different Periods

Prodromal Period	Anorexia, nausea, vomiting, weakness and fatigue Conjunctivitis, erythema, fever Hyperesthesia Ataxia, disorientation, shock Prostration, diarrhoea, abdominal pain Sweating, oliguria Paresthesia Coma, death
Manifest Illness Period	Anorexia, nausea, vomiting, diarrhoea, abdominal pain Abdominal distention, conjunctivitis, erythema, jaundice, fever Infection, purpura, haemorrhage, scalp pain, epilation Sweating, oliguria, weakness and fatigue, prostration, weight loss Hyperesthesia, paresthesia, ataxia, disorientation, shock Coma, death

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4.1.3 Radiation Induced Syndromes

A number of different syndromes can arise, subject to the severity of the exposure. These include –

Haematopoietic syndrome

- This occurs at skin doses between about 1 and 10 Gy and is sometimes referred to as the bone marrow (suppression) syndrome. The prodromal period is characterised by anorexia, nausea and vomiting, together with changes in the blood cells. The latent period lasts from about 2 to 20 days after exposure, depending on the dose. Even if this period is protracted, the period of depression of white blood cells is much the same. This is because there is a longer period of neutropenia with the higher doses, due to the rapid drop in the number of white blood cells and platelets and to recovery not commencing until about 30 days after exposure, regardless of the dose. There are brief rises in neutrophils after an exposure - the first within a day or so after the exposure and this is due to a stress response and the second at about 15 days when it may appear that the patient is recovering but this is due to the body's aborted attempt at increasing the number of neutrophils.

- As the lymphocyte count is a sensitive "clinical dosimeter", counts made every 6-12 hours in the first 48 hours after exposure will give an indication of the dose received. Counts of other cells should be made periodically throughout the course of treatment. If the lymphocyte count does not decline below 1200 mm^{-3} within 24 hours, the patient probably will not require clinical support; if it falls below 500 mm^{-3}, a severe course can be anticipated and if the lymphocytes disappear within 6 hours, the dose was fatal (see below).

Gastrointestinal syndrome

- This usually occurs at skin doses to the trunk greater than about 10 Gy. The prodromal period is characterised primarily by nausea, very severe vomiting and diarrhoea, which may be bloody. In the latter case, prognosis is usually death within 2 weeks, although, with treatment, individuals have lived for 36

- days. If the skin dose does not exceed 12 Gy, regeneration of the bowel epithelium is possible.

- In the manifest illness period, there will be gastric suppression, which means delayed gastric emptying, decreased gastric motility and decreased secretion from the gastric mucosa. Loss of fluids through diarrhoea, inability to absorb nutrients and infections caused by endogenous organisms can occur within a few hours to days following exposures of this magnitude. These symptoms are due to

- radiation effects on endothelial cells with resultant damage to intestinal microcirculation,

- delayed mitosis and/or death of cells that cover the villi of the intestines, resulting in damage to the epithelial barrier of the intestines,

- loss of the mucosal barrier that covers the intestinal lining and resultant loss of the colonisation resistant organisms that form the normal flora of the intestines and

- alterations in intestinal motility due to all of the above.

Cardiovascular syndrome.

- This occurs at doses greater than about 15 Gy with effects that are quite severe. The primary pathology is leakage of fluids into tissues. If there is leakage to the brain, there will be neurological symptoms. The cardiovascular and neurovascular syndromes can then blend together and the sequence of periods is very short. There would be vomiting, fever, hypotension and the skin may show erythema that comes in waves and could be easily missed. This latter effect would be caused by the breakdown products from the cellular membrane, causing changes in the vasculature, such as dilation of capillaries. It is believed to be due to the release of cytokines to the circulation.

- Fever is probably due to the release of cytokines into the blood stream. Leakage of fluids from the vasculature would also result in severe hypotension or lowering of blood pressure and leads to oedema of the brain, with subsequent neurological symptoms. Prognosis from this level of exposure is very poor and death occurs usually in less than two weeks.

Neurovascular syndrome

- This can occur at extremely high doses of the order of 50 Gy. There would be some temporary incapacitation to function within a few minutes (and certainly in less than 40 minutes). The effect is not so much the killing of cells but an effect on cell membranes - an electrochemical inactivation of the cells of the neurological system. Fever, prostration, prompt vomiting, with perhaps projectile vomiting would ensue. Death would be expected within a few hours - certainly within 48 hours at the most. There may be a very brief period of lucidity after the initial incapacitation, but then there would be other very severe symptoms before death.

4.1.4 Treatment

The treatment course for acute radiation syndrome will depend on the particular syndrome. The cardiovascular and neurovascular syndromes are invariable fatal. The gastrointestinal syndrome is usually fatal, particularly when resulting from higher doses, but it is not invariably so. Survival from the haemopoetic syndrome is much more likely. Appropriate treatment will assist recovery from the haemopoetic syndrome and lower dose gastrointestinal syndrome and will improve survival. Treatment to palliate symptoms should be given wherever possible, even when the chance of survival is poor. Prolongation of life has been seen with effective palliative treatment.

All treatment should be based on the patient's symptoms and needs and not on radiation dose. Reference was made earlier to the need for assessing the dose and this is aimed at assessing the syndrome for a patient and the regions of the body that are affected most. In the early period after an accident when dose estimates are not available, treatment will be determined according to the symptoms. Patients could be classified in the first place according to the following symptoms listed in Table 4.3. Treatment can be divided into three components - supportive care, control of infection and treatment of the haematopoietic system.

Table 4.3 Treatment as a Function of Symptom	
Symptoms	**Treatment**
No nausea, vomiting or diarrhoea Lymphocyte count above 1500 mm^{-3} at 48 hours. Probably no life-threatening injury	Observe periodically for any change in clinical status.
Nausea, mild vomiting; possible diarrhoea, conjunctival redness and erythema; Lymphocyte count between 800 and 1500 mm^{-3} at 48 hours.	Probably serious injury; plan for therapy.
Pronounced nausea and vomiting; possible diarrhoea, conjunctival redness and erythema; Lymphocyte count between 100 and 800 mm^{-3} at 48 hours.	Probably life-threatening injury; plan for maximum therapy.
Prompt severe vomiting and bloody diarrhoea ; erythema and hypotension Lymphocyte count below 100 mm^{-3} at 48 hours.	Almost certainly lethal; give supportive therapy.

Supportive care

Alleviation from vomiting is the first thing to be managed as this can last for some days. In using anti-emetics, it is desirable that other functions are not depressed whilst trying to control nausea and vomiting.

If there is vomiting and/or diarrhoea there can be significant fluid loss from the body with resultant dehydration. Monitoring of fluid and electrolyte balance is essential. Establishment of adequate venous access for the delivery of rehydration and other medication is an early priority.

If the gastrointestinal syndrome develops, with damage to the gastrointestinal mucosa, absorption of nutrients will be reduced. Attention to caloric intake and adequate vitamin and mineral supplements is necessary to prevent weight loss and aid recovery. Intravenous hyperalimentation may be needed to maintain caloric intake until gastrointestinal function recovers.

The damage to the gastrointestinal lining may allow normal gastrointestinal colonising bacteria to infect the body. Nonabsorbable antibiotics can be given to reduce this source of infection. Growth factors, which act on the gastrointestinal epithelium, may aid recovery.

Control of infection

Control of infection is important throughout the syndrome period as a reduced number of white cells increases the risk of overwhelming infection. During the latent period, a complete physical examination of the body should be made to locate any potential sites for infection, e.g., decayed teeth, skin infections, fungal or viral infections. The patient should be treated for these and put into optimal condition to survive the period. Consideration should also be given to sending the patient home during the latent period as this would reduce the possibility of ihospital acquired nfection, and then be brought back into hospital when further problems are anticipated.

Whilst the patient is in hospital, if the neutrophil count is < 1000 then strict isolation procedures should be observed at all times. These may involve the use of reverse isolation procedures, complete enclosure units or laminar airflow units. The following may also be needed -

- antibacterial agents, wherever indicated;
- antiviral agents, as necessary; they should not be used preventatively, unless viral infections are anticipated. In

this regard, the herpes virus can become activated two or three days after exposure and herpes infection in the mouth, nasopharynx and skin should be avoided. Acyclovir or similar might be indicated;

- antifungal agents, as necessary; the mouth and nasopharynx can be very much affected by yeast infections - redness, irritation and ulcer formation can be reduced by these agents; and
- anthelmintics, as necessary for parasite infections.

In managing patient care, the number of invasive procedures, such as catheters in the bladder or blood vessels, should be limited to those absolutely necessary; by this means, the number of entry pathways for bacteria into the body is minimised.

Treatment of the haematopoietic system

Because there is generally non-uniform exposure of the body, there could be a number of stem cells in the bone marrow that remain intact; they can repopulate sufficiently for the patient's recovery provided adequate supportive care is given. If as many as ten percent of the stem cells remain intact, the blood cells will repopulate. In general, physicians would use the same skills they use in taking care of a patient who experiences neutropenia, lymphopenia or thrombocytopenia resulting from cancer therapy. Consultation with a medical specialist in this field is advised (Medical Oncologist or Clinical Haematologist).

Treatments that can be given to survive the period of haematopoietic depression include several cytokines and colony stimulating factors that increase the number of white cells in the blood. Some of these cytokines, such as GMCSF (granulocyte macrophage colony stimulating factor) may cause granulocytosis where there is an initial drop followed by an increase in white blood cells. There is no acute toxicity associated with this, but with some administrations, bone pain has been reported although, so far, this has not been severe. GMCSF produces more granulocytes and macrophages and also has an effect in making the cells better at killing bacteria and performing their functions in the body. Its performance seems, however, to be much better for higher than for lower dose patients.

In the haematopoietic depression period, spontaneous haemorrhage is more likely to occur at platelet levels below 30,000 mm^{-3} and. platelet transfusion is indicated. In some cases, multiple transfusions may be required.

In the event of a high dose of penetrating radiation giving an acute uniform exposure to the trunk, so that most of the bone marrow is irradiated, recovery from the ensuing haemopoetic syndrome is doubtful or at least likely to be very prolonged. Transplantation of bone marrow stem cells may shorten the period of cytopenias and assist recovery. A suitable HLA match donor must be available for bone marrow transplantation. Subsequent problems can arise after bone marrow transplant if the patient has their own stem cells, which recover, and the transplant is not a perfect match, resulting in the development of graft versus host disease (GVHD). Also there is the possibility of subsequent development of radiation pneumonitis, of pulmonary complications associated with the transplant and of cytomegalovirus (CMV).

It is possible to harvest bone marrow stem cells from the peripheral blood of a donor suitably pretreated with GCSF which may facilitate donation from a matched donor. Another source of stem cells is from placental cord blood. Each of these collections is small and thus repopulation of the bone marrow from this source for a normal sized adult is very slow.

There is a set of conflicting data on the usefulness of bone marrow transplants in this kind of situation and only a few patients have shown proven benefits from it. At the present time, it is only used as a last resort in the treatment of severe haematopoietic depression except in the unusual circumstance of the availability of an HLA identical donor such as an identical twin.

4.2. Local Radiation Injury

4.2.1 Body Regions Affected

Local radiation injury may occur when high radiation doses are delivered to small areas of the body in a short period of time. Most accidents have involved equipment such as X-ray diffraction units, where operators have inadvertently placed their fingers or hands in the direct X-ray beam and industrial radiography equipment, where the radioactive sources have become detached, picked up (often by a member of the public) and placed in pockets and left there for some days. In addition, there have been some misadministrations (of doses) to patients undergoing radiotherapy. In most cases, very high doses have been delivered to superficial tissues, with a rapid drop-off in dose as the radiation penetrates further into the body.

As only a relatively small volume of tissue is affected in these accidents, the normal functions of the body would be expected to continue after the exposure. Systemic changes, if they occur in individuals, are mild in comparison to those of the acute radiation syndrome. Symptoms such as nausea and vomiting that occur in the prodromal period of the acute radiation syndrome may also occur if the local area irradiated is the epigastrium or, in the case of the head, doses of the order of 300-400 Gy are involved. Generally, major organs and organ systems are not involved in these injuries, although there may be some situations where necrosis of bone, muscle and other internal organs occurs.

The skin is the tissue most likely to demonstrate change following a high dose to a small area. The severity and time of onset of any such changes will depend on the dose received - the higher the dose, the greater the severity and the earlier the time of onset. In addition, the effect will depend on the skin area involved - the smaller the area, the higher must be the dose to result in a particular change. It will also depend on the body region involved. For example, the most rsensitive areas of the skin are those that are moist and subject to friction, such as the axilla, groin and skin folds; less sensitive areas include the general body skin and the least sensitive areas are the nape of the neck, scalp, palms and soles. The variations are mainly due to the different thicknesses of the epidermis. In addition, the acute skin reaction is fairly independent of skin colour and type and age of patient.

4.2.2 Types of Early Injury

Following a high dose of radiation to a small area the skin is almost invariably injured and the changes there are most visible. Adjacent local tissues may also be injured depending on the nature of the radiation involved in the accident.

The effects likely to arise from acute exposure within a few weeks are

Epilation.

The minimum dose for this is about 3 Gy. It appears about 17-21 days post-exposure and may continue for several days thereafter. For single doses above about 7 Gy, loss of hair may be permanent. The different hair bearing regions of the body vary in the dose required for permanent epilation.

Erythema.

The threshold dose for this to appear depends on the radiation energy and is about 3 Gy for 100 keV photons and about 6-10 Gy for 1000 keV photons. It may appear within hours or within one or two days, remain for a short period of time and then disappear. It also appears about 2-3 weeks post-exposure, lasting for about 20-30 days. The early erythema may give a sensation of warmth and be present for some time, in contrast with the episodic erythema associated with the acute radiation syndrome. At 15-20 Gy, the skin may also show hyperpigmentation or bronzing. This can be used as a good indicator of dose fall-off below 15 Gy.

Dry desquamation.

This may occur in the dose range about 10 - 15 Gy. It appears about 2 - 4 weeks post-exposure. During this time the basal area underneath the area is repaired and the epidermis remains relatively intact.

Moist desquamation.

This may occur in the dose range about 20 - 50 Gy. This appears about 3 - 4 weeks post-exposure and small blisters may coalesce and then rupture.

Blisters.

These can arise in the dose range about 20 - 50 Gy directly from exposure, as distinct from those following wet desquamation. They appear about three weeks post-exposure, with well defined edges and will often remain intact if not interfered with. They are mainly caused by small X-ray beams, such as those from X-ray diffraction units.

Hyperpermeability Syndrome.

A large dose or radiation to a moderate to large area of the skin may result in rapid loss of fluid and protein into the skin and subcutaneous tissues occurring acutely. This is due it increased vascular permeability in the blood vessels in the damaged tissue. Major and potentially life threatening symptoms may occur from the resultant local oedema and increased tissue turgor possibly compressing airway or blood vessels.

This loss of protein and fluid into injured tissue can lead to depletion of the circulating blood volume, with associated shock and renal failure. Attention to restoration of blood volume is needed.

The acute management of these sever skin injuries and the systemic complications arising from them are similar to the management needed for sever thermal burns. Patients with this type of injury are ideally managed in a facility which has the resources and medical expertise associated with a specialist thermal burns unit.

Radionecrotic lesions.

The threshold dose for these is greater than 50 Gy, although 100 Gy is often required to produce them. They may appear any time between a few weeks and about three years post-exposure, but for higher doses - 200 or 300 Gy, they may appear in 3 to 7 days post-exposure. In the latter case, if the lesions are in areas of body hair, epilation as well as sloughing of tissue will occur much earlier than normal. In cases of extremely high doses (of the order of 10^4Gy), the eschar tissue can become extremely hard and difficult to penetrate. The margin round the area can break down and slough off and there will then be areas of re-epitheliation and haemorrhagic islands.

Other effects.

Important organs in the subcutaneous tissues (nerve endings, hair follicles, sweat glands) may be damaged and there may be some form of tenderness, itching or tingling and a changed sensitivity to heat and cold. Doses of the order of 70 - 100 Gy are neede to cause these symptoms. They may develop very early (hours) post-exposure. In addition, there may be some restricted motion or stiffness in irradiated fingers, for example, and swelling of tissues (oedema), which may be seen within a few hours up to 20 days. Episodic erythema, as in the acute radiation syndrome, may also appear.

The effects seen are dependent on the type of radiation involved. For example, with β particle exposures, there is very rapid absorption in the first millimetre or two and this can result in dermal necrosis. This is not so likely for the same dose of more penetrating radiation. Underlying tissues are not likely to be affected with beta radiation and things like oedema and vascular changes are unlikely. However, beta particles of low energy may not even reach the dermal plexus and any effect would be quite small. A knowledge of the radiation type and energy is therefore useful in trying to determine the likely depth of the injury.

It is important to recognise that some injuries, particularly those resulting from high doses, may take months or even years (in the case of moist desquamation) before the tissue is stabilised, even with treatment.

4.2.3 Late Effects

Late effects may be seen in all irradiated tissues. The changes seen are related to the dose of radiation received and the amount of the organ exposed to irradiation. Late effects arising from local radiation injuries develop insidiously and progressively over time and result from progressive tissue atrophy, fibrosis, reduction in vascularity and depletion of functional parenchymal cells from the tissue. These changes arise from radiation injury to the blood vessels of the organ as well as direct radiation injury to the parenchymal cells of the organ. The changes develop progressively over months to years. In general the higher the radiation dose the more severe the changes and the earlier they appear.

In the skin the late effects seen include pigmentation, hypopigmentation, atrophy, fibrosis and telangiectasis, reduction in sebaceous gland secretion and epilation. Dermal changes include atrophy, fibrosis and depleted vascularity. These changes take months to years to appear. The skin becomes more susceptible to injury from minor trauma and may be slow to heal. Chronic ulceration of the skin and necrosis may occur if the vascular damage is sufficient.

Skin and dermal atrophy and fibrosis as well as direct damage to sensory nerves can result in increased sensitivity to temperature changes as well as touch and trauma. Fibrosis and atrophy of subcutaneous connective tissue may result in stiffness and limitation of movement at joints. Such injury may also be seen in tendon sheaths, ligaments and muscles restricting movement. Development of radiation induced cancer may occur after many years, although this risk is not high. In the skin, radiation induced cancer has not been observed in the absence of the changes of chronic radiodermatitis.

Other tissues, which are particularly susceptible to local radiation injury, include the eye and the testis. The cornea and conjunctiva are of similar sensitivity to the skin and may develop telangiectasis and scarring as late radiation effects. This scarring can lead to blindness. Cataracts are the most frequent late effect in the eye. The majority of radiation induced cataracts are nonprogressive and do not impair vision. The incidence of cataract is dose, time, and age dependent and on average appears 2-3 years after exposure. Neutron exposure is more effective at producing cataracts than photons.

Local radiation exposure in the groin region in the male may result in temporary or permanent sterility. Temporary sterility in males may occur with single doses of 1.5- 4.0Gy and permanent sterility with single doses of 5.0-9.5Gy. Sterility may be temporary but exist for a matter of years. In most cases there may be abnormalities in spermatozoa, but libido and potency are unimpaired. In females local radiation injuries are less likely to give sufficient dose to the ovary to impact on fertility because of the intra-abdominal location of the ovary.

4.2.4 Treatment

Treatment of local radiation injuries can be a "wait and see" procedure. In many instances, it may be better not to do anything, but let healing take its course. This is particularly the case if the skin is intact and there is no pain associated with the injury. This applies mainly to epilation, erythema, dry desquamation and intact blisters where there is no weeping of fluids round the margins. In these cases, it is important to keep the injury clean and free of infection; irritation and damage to the skin should be avoided. To this end, there should be no scrubbing of the area with soap and detergents, no cauterisng, no use of irritating solutions and no exposure to the sun. However, for dry desquamation, applying a mild lotion and covering with loose fitting clothes can be helpful - generally lubricating and soothing creams such as sorbelene cream, Vitamin E cream or Aloe Vera gel are preferred. Cortisone containing preparations are not used as they slow the recovery responses. Antibiotic preparations are only indicated if infection is present. The use of topical antibiotics promotes the development of antibiotic resistant infections.

For other conditions, the treatment will depend on the site, the dose, the radiation type and on any resulting pain. Pain can be significant, particularly if there is infection or broken skin. If areas of skin are exposed to high doses, there is often little that can be done medically to save the tissue. When doses likely to result in ulceration occur, treatment in the acute phase is generally symptomatic and can be approached by simply maintaining cleanliness and trying to prevent infection with antibiotic ointments. For painful skin conditions, adequate analgesia should be provided. Any signs of infection should be treated early and intensively by the use of appropriate systemic antibiotic therapy. If soft tissues across a joint are involved and there is a risk of soft tissue contraction and fibrosis, immobilisation of the limb in a position of function may assist with healing and be a basis for later rehabilitation.

Quite often, "burns" resulting from radiation exposure have the same appearance as thermal burns, but different treatment is required. Accordingly, the condition causing burns should be determined. With thermal burns, the causative agent is obvious and the effect immediate. The same applies to chemical burns. With radiation burns, the causative agent is often not recognised immediately and the ensuing damage may not be apparent for hours, days or even weeks after the event causing it.

Whilst small areas of skin necrosis and loss will heal with re-epithelialisation by ingrowth of cells from surrounding undamaged skin, larger areas of skin loss may need to be repaired by other means. Consultation with a plastic surgeon experienced in the management of radiation injuries is advisable. Usual surgical techniques for the repair of tissue defects can be adapted for use. Understanding of the progressive nature of the tissue injury and damage, both to adjacent tissue and the vascular supply needs to be included in deciding the appropriate repair technique in each particular case.

Surgery to repair skin defects is undertaken to cover the area, relieve pain, restore function and alleviate the effects of severe radiation dermatitis. A prerequisite for any surgical attempt is the absence of infection in the area. In general full thickness skin flaps with their own blood supply are preferred as they heal more certainly and give a better functional result, but for large areas split skin graft may be used. However, the timing and success of skin grafting is dependent on any damage to the underlying vascularity.

To assess vascular status, useful methods include arteriography, radionuclide perfusion studies and thermography. Vascular injury can be exacerbated by physical trauma, histamines, prostaglandins and arachidonic acid derivatives. Administration of an antiprostaglandin drug and topical application of a thromboxane inhibitor, anticoagulants and antifibrotic drugs have been suggested, but the efficacy of such treatments is still in the research stage.

Severe tissue necrosis may not respond to treatment and gangrene could set in. Treatment usually requires amputation or removal of the offending area. Such action may be seen to be necessary in the early stages of the symptoms, but most patients who face the possibility of amputation resist application of this procedure until such time as ulceration or gangrene become so severe that it is seen that there is no likelihood of success of the more conservative methods of treatment and amputation is the only option.

4.3 Combined Injury

Combined injury is defined as a concurrent trauma, whether it is physical or thermal injury, and radiation injury occurring in the time prior to recovery of any one of the injuries. It increases the probability of death from radiation injury or results in a longer recovery period or a less successful outcome than would otherwise be the case. Effects arising from radiation exposure may become apparent at a much earlier time and be much more severe when other injuries are present.

In determining the history of a radiation accident, it is important to determine if there have been any injuries or illnesses in prior months that have not completely healed. This information needs to be taken into account even if the injury or illness affected different parts of the body from the region exposed in a radiation accident. The patient must be told to ensure that he/she reports any injuries or illnesses, no matter how trivial that occur whilst undergoing observation or treatment for a radiation accident as these may affect the treatment course. Any treatment prescribed for that, injury or illness may need to be different to that normally prescribed for the condition.

With combined injury, effects may be manifested earlier than normal and it will not be known if the symptoms are due to the radiation exposure or to trauma. For example, in the prodromal period of the acute radiation syndrome, the symptoms may give a false indication of dose due to early and more severe nausea and vomiting, which, in turn, could lead to a different prognosis and treatment course. The absolute lymphocyte count may also drop because of trauma - burns and serious trauma are known to cause lymphopenia and any such drop can lead to false assessments of the radiation dose received.

Both radiation and trauma impede repair of cells, affect the immunological system and affect the ability of the body to survive an infection. With bleeding, there will be an earlier deficiency of red blood cells and the onset of pancytopenia will be hastened. Transfusions given to make up for loss of fluids and red blood cells may also affect subsequent treatment. There will also be significant increases in the amount of thromboxanes, prostaglandins, products of cellular metabolism and break-down products of arachidonic acids in the body.

Where surgical procedures on major injuries and life-saving procedures are needed, these should be carried out within 36-48 hours, a period when there are still some white blood cells present to fight infection. Elective surgery should be postponed as long as possible. Any surgery to repair defects and for reconstruction should also be left as long as possible, possibly 7-8 weeks after exposure. The risks of infection should be at a minimum when these surgical procedures are undertaken. If thermal burns are involved, early excision of potentially septic tissue may be desirable, with early closure of the wounds, preferably by skin grafting.

In a combined injury haemorrhage and infection remains the major problem. Consultation with a haematologist and infection control specialist will be needed. When transfusions are needed all blood cells need to be irradiated with doses of the order of 15-20 Gy to remove any T cells that might be present in the blood. If surgery is needed the platelet count should be at least 75,000 mm-3, somewhat higher than that needed under other circumstances. Platelet transfusions may be given to ensure this level.

To address the risk of infection, as with the management of the acute radiation syndrome, an initial examination of the patient to detect any sources of possible bacterial, viral, fungal and parasitic infections should be made. Appropriate drug therapy to eradicate potential pathogens should be implemented. Measures used in the care of granulocytopoenic (immunosuppressed) patients should be implemented. Good personal hygeine is necessary e.g. topical antiseptic agents (e.g. iodine) in the anal and vaginal regions, hair shampooing, good cleaning of feet, toe and finger nails, umbilicus, etc. It is important however not to traumatise skin which has been affected by radiation. Good oral hygeine is also important; mucositis occurs frequently in association with these symptoms. Other methods to minimise infection involve food precautions with fresh fruit and vegetables being avoided, implementation of isolation procedures (reverse barrier nursing), laminar airflow unit, etc.

Controls to manage gastrointestinal problems can be used in a number of ways. Early controlled oral nutrition should be implemented, if possible, but it may be necessary to use intravenous hyperalimentation to maintain the caloric requirements. The sooner enteral nutrition is implemented the better, as maintenance of gastric acidity and enteral nutrition are important in preventing infectious organisms making their way from the gut to the respiratory tract and resulting in death. Administration of something like sucralfate to minimise the possibility of stress ulcers should be considered.

Growth factors can be tried to stimulate cell recovery, but they have not yet been proven to have any additional benefit in combined injury compared to that in radiation injury so far. Immunomodilators, such as the use of glucans and triacidmyaclomates have been suggested, but they are still in the research phase. Improved nutrition and clinical support are obviously indicated and certain vaccinations might be helpful in the early stages.

Some long-term problems can occur following recovery. There is still the possibility of radiation pneumonitis occurring, which may be confused with respiratory distress syndrome. There is also the potential for problems with cytomegalovirus. In addition, the possibility for tissue atrophy, etc. will be much greater than that for radiation injury alone.

5.0 MONITORING OF INDIVIDUALS FOR RADIOACTIVE CONTAMINATION

In order to put into effect appropriate procedures for decontamination of individuals, early determination of the extent of the contamination on and in their bodies is essential. For this, external contamination is assessed by direct monitoring of an individual's skin and clothing and internal contamination, usually by monitoring biological samples taken from him/her.

Some preliminary external monitoring and sample collection and measurement should be carried out at the scene of the accident as soon as possible after the accident. This makes it possible to undertake preliminary decontamination procedures and should indicate an order of priority for later procedures. Repeat and more detailed monitoring and biological sample analysis would be carried out at the hospital before, during and after the procedures; these may indicate modification to the procedures already decided upon or set in train.

The implementation of decontamination procedures should never be delayed whilst awaiting results of detailed monitoring as some of these results may take a few days to obtain. Early implementation of procedures could remove a substantial fraction of the contaminants in the waiting period.

5.1 General Radiation Monitoring Procedures

Portable contamination monitors, such as proportional, scintillation or geiger counters are used to locate contamination deposited externally on the body. The monitor chosen must be able to respond to alpha or beta particles, whichever is present, and should have a small enough window thickness to reduce particle absorption to a minimum. Where β and γ emitters are present, measurements should be made with an unshielded window so that both β particles and γ-rays are counted. The shield can be put in place and measurements repeated if discrimination between these is necessary.

Information on the radionuclide(s) present is necessary for proper monitoring and assessment. This should be available at the scene of the accident, but if it is not, samples of the contamination will have to be measured on more sophisticated equipment. When this information is not available, a monitor that responds well to the radionuclides present can be used initially for locating contamination or demonstrating effectiveness of decontamination, but as radionuclide identification become available, a more appropriate monitor may be necessary, particularly to demonstrate that contamination is below a prescribed value.

- Monitors should be checked for proper performance before any measurements are made (see Section 2, Chapter 11)., Once this has been established, the most sensitive range (x l) should be selected to check the background radiation level. Subsequently, measurements should be made using the highest scale setting; this setting should be reduced as readings fall below 10 per cent of the maximum scale value.

- Measurements of background radiation should always be made before the monitoring of individuals commences; if the background levels are high, as they could be after an accident, false indications of the contamination on individuals could arise. Wherever possible, monitoring of individuals should be carried out in areas where, should there be any high background levels, they will have least effect on the monitoring results.

- In some cases, it may not be possible to move a victim to an area of lower background radiation, particularly if he/she is suffering from an injury or illness that precludes his/her movement. Monitoring should then be carried out where the victim is at the time, with any shielding available being utilised. If the person doing the monitoring stands between the area of high background radiation and the victim, this helps shield the monitor from the higher levels. However, on no account should monitoring or the collection of biological samples impede the implementation of life-saving procedures, although in some cases, these activities can be carried out concurrently.

- Monitors with large windows of 30-100.cm^2 area should be used initially, followed by others with smaller windows to pinpoint regions of contamination. This is particularly the case for measurements near the eyes, wounds, etc.

- Problems may arise in measuring α-emitters if small amounts of water, perspiration, blood, wound fluid, hair, flakes of skin (including finger nails) or small pieces of tissue are present, as these can absorb the alpha particles; α emitters may then not be detected. Any moist areas containing α emitters should be dried before measurement. Any material used for blotting skin or wounds dry should also be checked for alpha contamination.

- The face of the detector should be kept close to the skin and clothing, but not so close that contact is made, thereby contaminating the detector and making it useless for further measurements. Placing the detector in a plastic bag can be helpful in preventing it being contaminated should it contact contaminated areas or be splashed with contaminated blood or liquid. The plastic bag can be removed later when detailed contamination checks are required. Care must be taken that the plastic does not significantly absorb any α particles present, and this should be checked prior to use.

- Results of all monitoring, together with sites of wounds etc., should be carefully recorded in notes or on a body chart and these referred to as decontamination proceeds, and each area should be monitored carefully to evaluate the effectiveness of the procedure. Special attention is needed if α emitters are present in wounds; a zero monitor reading may not mean the procedure has been successful. All material used for blotting dry should be monitored as a double check.

- All biological samples collected from the victim, as well as any dressings, smear pads, etc. should be placed in individual, labelled plastic bags for later measurement and analysis.

5.2 Monitoring of External Contamination

5.2.1 Skin and clothing

Radioactive contamination may be deposited on the skin and clothing as a result of a radiation accident; as much as 70 - 80% of this contamination could be on the outer clothing. The most likely parts of the body contaminated externally would be the hands and face (including body orifices), with less likely areas being the head, neck, hair, forearms, wrists, legs and torso. If the radioactive material is in liquid form, it could penetrate clothing, thereby increasing the possibility of contamination being on some of these latter parts of the body.

The levels and positions of contamination on the body and clothing should be determined with measurements being made from head to toe, in a slowly moving sideways, descending manner. The rate of movement of the detector should be slow enough (about 2-3 cm per second) to respond to any contamination present. The front and back should be monitored with arms outstretched. The arms, hands (both sides), soles of the feet and head should also be checked. A diagram showing the movement of a detector over a person is shown in Fig. 5.1. In some situations, because of the victim's condition, it is not always possible to carry out a complete survey, but all accessible parts of the body should be checked. Filter papers, gauzes, etc. may also be used to collect smear samples from the skin and these can be analysed later.

5.2.2 Wounds

Uncovered wounds should be monitored for contamination, but alpha particles could be absorbed in wound fluid and there could be an incorrect indication of the presence of alpha emitters. In these cases, sterile gauze could be used to wipe the wound carefully and then dried before measurement; wound fluids may also be collected in droppers or syringes. Any scabs removed from wounds should be placed in individual, labelled plastic bags for later analysis. Most dressings would be best left in place, unless removed by a medically trained person. In these cases, wounds should be dressed again; if a dressing is not removed it may be desirable to cover that dressing with another one so that any contamination on it is contained.

5.2.3 Body orifices

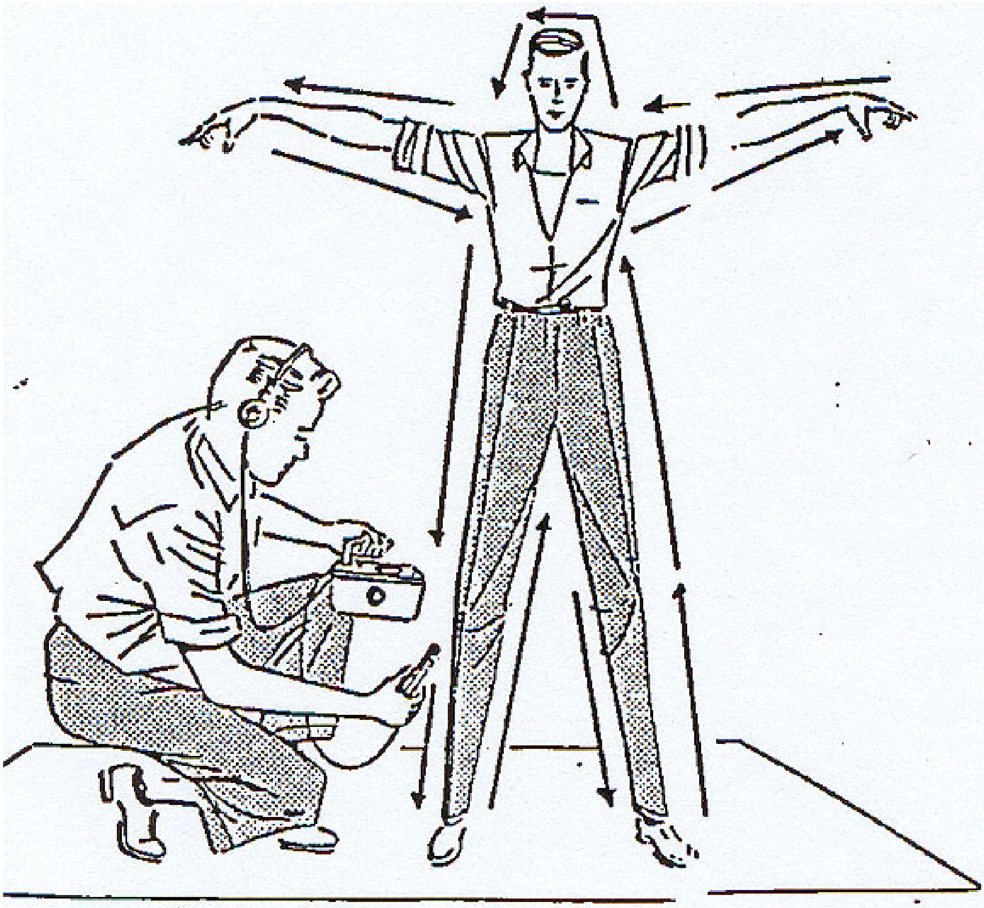
Nasal and oral swabs, taken on moist, clean cotton-tipped applicators and any sputum and vomitus should be collected at the scene of the accident. In addition, any tissues, etc. from nose blows should be collected. Quick measurements can be made on these to give an early indication as to whether any intake of radioactive material was likely to have been large or small. This assists in planning decontamination procedures.

The following procedures are recommended for personnel monitoring (see Fig 5.1):

- Have person stand on a step-off pad.
- Instruct the person to stand straight, feet spread slightly, arms extended with palms up and fingers straight out. Have the subject turn around, and repeat the survey on the back of the body.
- Monitor the soles of the feet. Monitor both hands and forearms to the elbows with palms up, then repeat with hands and arms turned over.
- Starting at the top of the head, cover the entire front of the body, monitoring carefully the forehand, nose, mouth, neckline, torso, knees, and ankles.

Swabs should be taken within about 10 minutes of the accident as radioactive contaminants in the mouth and nose can be taken into the body quickly. In the nose, for example, any deposit near the mucocutaneous junction can remain there for about 60 minutes or longer, but any 2-3 cm above the junction can be cleared and swallowed within about 10-20 minutes. It should be noted that if only one nostril is contaminated, the possibility of inhaled material is reduced; it is more likely that the nose has been touched with a contaminated finger. If the swabs show several hundred or more counts/minute, there is a possibility of a large inhalation but if only tens of counts/minute, the inhalation was probably low, but this can never be a guarantee. If α-emitting radionuclides are involved, the swabs should be dried before measuring them as any fluids will absorb the alpha particles, leading to low count rates.

Fig 5.1 Procedure for checking external contamination



5.3 Other Relevant Action

After completion of the initial survey of the victim at the scene of the accident, his/her contaminated clothing should be removed, if possible. This reduces the spread of contamination during transfer to and at the hospital. At times, only part of the clothing can be removed, due to the victim's condition. Procedures for removing clothing and handling the victim are given in *Chapter 2.*

Following removal of clothing, a detailed medical examination for skin wounds and other injuries should be made as these will need medical attention; detailed monitoring should be made of any wounds which show as a result of this examination and any other previously covered parts of the body should be checked for contamination.

5.4 Monitoring of Internal Contamination

Portable contamination monitors can be used to detect some γ emitters within the body (provided sufficient activity is present), but they cannot detect γ or γ emitters. In addition, because of the translocation of radioactive material within the body after an intake, particularly in the first day or so, these monitors cannot be used to locate the position of material with any accuracy at any given time. It should be noted that it may not always be possible to differentiate between external and internal contamination.

For location of contaminants within the body, more sophisticated equipment, such as γ cameras, as used in nuclear medicine departments, thyroid counters and whole body monitors are required. These cannot be used to measure α or β emitters in the body, but in some cases, beta emitters such as ^{90}Sr can be measured by whole body monitors by counting the Bremstrahlung emitted. For other β emitters, the γ-rays emitted by daughter products in the decay series can be counted. The number of these monitors throughout the world, is low, as they are expensive equipment and require a very well shielded room to reduce background radiation levels to the lowest possible level. Two are in use in Australia - at ARPANSA, Melbourne and ANSTO, Sydney.

Because of their complexity and location relative to the accident and emergency departments of hospitals, this equipment cannot be used during the decontamination procedures. Their main use is in determining the activity of a contaminant left in an organ once the procedures have been completed. From this, the dose to an organ can be derived and hence, the risk of long-term effects of the material left in the organ can be assessed. A repeat of the decontamination procedure or alternative procedures could be undertaken at that stage, if it was thought desirable.

An assessment of contaminants remaining in the body can often be derived from monitoring of biological samples. These include urine, faeces and blood. Monitoring of excreta, however, only indicates what has left the body. Modelling can give the quantity left within the body, but this may be subject to gross errors due to the physiological variability between individuals. Blood samples should be taken from uncontaminated parts of the body, if possible. The venous puncture sites should be dressed immediately afterwards to prevent the ingress of any contamination.

With urine and faecal monitoring, the results depend on the intake time of the radionuclide, the chemical form and its solubility and, for inhaled material, the particle size. In addition, excretion rates may vary from one individual to another as does the fraction taken up by the various body organs. For example, a total transit time in the gastrointestinal tract of 24 to 36 hours may occur in an active person who eats a high fibre diet and has adequate fluids, whereas a period of 5 days or more may be experienced by a less active individual on a low fibre diet with a low fluid intake *(Chapter 14).*

Except for radionuclides such as iodine and tritium, there is little point in carrying out urine analysis within the first three hours of an accident to assess intake. For proper monitoring, it is often safer to ignore the first couple of samples after intake as these may be diluted with uncontaminated urine already in the bladder, although the first samples may be needed to establish base-line values and that the kidneys are functioning properly. Following that, the total urine excreted each day should be obtained and monitored for at least four days. From the results, it is possible to extrapolate backwards to the time of intake and obtain the actual intake, after allowance is made for the fraction of the material retained in the body. Similarly for faecal monitoring, but a few days may need to pass before collection.

Monitoring of urine and faeces can also be useful for judging the effectiveness of various agents used for decontamination of the gastrointestinal tract. Once radioactivity levels in samples reach a level that does not change significantly with time, then the treatment is not achieving any further improvement in decontamination. Changes in the blood counts arising from the intake of radioactive material are not likely to be significant in most cases. Only in the case of very large intakes are detectable changes likely to occur and these will be similar to those for large external exposures *(Chapter 13).*

6.0 CONTROL OF RADIOACTIVE CONTAMINATION IN A HOSPITAL

Whenever a radiation accident victim is brought to a hospital and has radioactive contamination on the skin, in the body or both, there is the possibility of contamination being spread over parts of the hospital and pieces of equipment and other items becoming contaminated. In addition, people involved in the management of the victim in the hospital, as well as those bringing him/her to the hospital may become contaminated. Considerable control must therefore be exercised to ensure that such contamination is minimised.

One of the basic principles for reducing the spread of contamination is to leave as much of it as possible at the scene of the accident. To this end, any contaminated clothing should be removed from the victim and left there, if possible. There are times when this cannot be done and greater care is then necessary in the hospital to minimise the spread of contamination.

A radiation accident victim may arrive at the hospital with a considerable amount of contamination on him/her. This may be because -

- those at the scene of the accident did not have any equipment for monitoring the contamination;
- decontamination was commenced, but time or deterioration of the victim's condition did not allow further removal of contamination;
- only partial decontamination or removal of clothing was undertaken because movement of the victim was difficult or dangerous due to other injuries or trauma; or
- no attempt was made to remove clothing.

Accordingly, accident victims who are likely to be contaminated should always be considered to be extensively contaminated on arrival at the hospital unless those at the scene of the accident advise otherwise or outer clothing has been removed.

As it is expected that there would be some forewarning of the arrival of a contaminated accident victim, advance preparation should be undertaken at the hospital. If a victim arrives without forewarning, a great deal of contamination could occur and a greater clean-up effort of areas, equipment and people will be necessary, but this can be managed.

Controls should be instituted to minimise the spread of contamination. For patients with external contamination and those with internal contamination and who are to undergo lavage and such like, the controls are outlined below. If internal contamination only is involved, and this will be rare, contamination will occur in excreta and body fluids and these should be collected, with care being taken not to contaminate staff, outside of containers, etc. A number of, but not all, the controls indicated below should be followed in these cases.

6.1 Designated Areas

The area designated for entry, triage and treatment of patients should be away from the main traffic. area and large enough to cope with the number of patients expected. If any patients need the application of life-saving procedures, facilities for this should be in the area, or nearby, so that they can be treated immediately upon arrival at the hospital, regardless of any radioactive contamination on them.

In the event of contaminated and non- contaminated patients arriving from the accident scene, they should all be admitted and triaged in the same area, but the non-contaminated patients should be directed through the normal accident and emergency department procedures only after thorough monitoring has shown them not to be contaminated.

The entry, triage and treatment areas should be prepared in advance of patient arrival and be designated as controlled areas. For this, the following should be done -

- cover the entire floor or a large enough area to allow comfortable working space for several people and equipment with plastic or paper, taping down all edges to prevent tearing and tripping. If plastic is used, it should be "non-slip" or covered with other material which should also be taped;

- cover the floor from the ambulance entry to the reception area in the same manner (if this distance is large, see under "Procedures" for an alternative approach to this);

- remove from the area any movable items that are not required. Cover non-movable items with plastic or paper;

- cover door knobs, light switches, etc., with pieces of plastic or plastic bags and tape;

- restrict access to the covered areas, ambulance entry, etc. by the use of signs, ropes and/or security officers;

- where necessary, create a buffer zone to separate "clean" and "contaminated" areas. This will restrict "onlookers" and allows an area for storage of items that may be needed; and

- confine public relations exercises to other parts of the hospital, well away from the controlled area.

6.2 Protective Clothing

Protective clothing should be worn by all persons in the controlled area. In general, the normal clothing used in theatres should suffice - surgical gowns, masks, caps, gloves and overshoes. Gowns should be waterproof, but if not, large plastic aprons worn over them are satisfactory. Lead-plastic aprons, as used in X-ray departments are not satisfactory for these procedures. Plastic bags can be taped over shoes if waterproof overshoes are not available. The cuffs of trousers should be taped and secured to the inside of overshoes. Face masks are rarely required to protect against airborne contamination; they are mainly to protect the face from being touched by contaminated gloved hands, with the consequent risk of intake of contamination into the body.

- Two pairs of gloves should be worn. The inner gloves should be surgical gloves taped on to the sleeves of the surgical gown and should remain there for the entire procedure unless damaged. The outer gloves may be surgical or plastic gloves and are not taped down as they should be changed whenever they become contaminated.

- When taping clothing together, always leave a tab on the tape to help its removal.

- All team members should be trained in the proper manner of removing protective clothing so that they do not contaminate themselves, others or equipment in such removal (see Section 6.4).

As there may be more than the usual treatment team present, some identification of personnel on the gowns or caps can be helpful.

6.3 Facilities Required

- **Trolley** - if used, a plasticised paper sheet or a linen sheet with rubber or plastic underlay should be spread over the trolley before the patient is moved on to it.

- **Table** - a regular treatment table usually suffices. The patient can be transferred directly from the trolley on the plasticised paper sheet or on the linen sheet (with underlay) to the table; otherwise, the treatment table should be covered with these. (Some hospitals use special tables on which patients can be hosed down initially, so as to wash off radioactive material or chemicals, or if they are suffering from heat shock. The design of such tables should allow for run-off water to be collected; they should be made of non-metallic material, in case electrical equipment has to be used.)

- **Waste receptacles -** there should be several of these. They should be lined with plastic bags for "soft" contaminated wastes and be solid disposable receptacles for hard objects such as glass, syringes, etc. Some receptacles will be needed for liquid wastes and possibly for patient's excreta (if contaminated). These and irrigating solutions may be measured after the procedures.

- **Plastic bags** - a good supply of these is essential. Large bags should be placed in waste receptacles; they can be used for the floor coverings after "clean-up", sheets, plastic items, etc. ; medium size bags for patient's clothing, valuables and personal items, protective clothing, etc. and small bags (sandwich size) for collection of samples for subsequent measurement and analysis. The latter bags should contain one sample only and be carefully identified.

- **Survey instruments** - as many as are necessary for staff trained to use them and of a type suitable for the radionuclides involved.

- **For patient care** - drapes, tape, absorbent towels and pads, irrigation solutions, long handled forceps and other surgical items, which may need to be changed if they become contaminated.

- **Others** - life saving and investigational equipment - electrocardiogram, defibrillator, mobile X-ray unit, etc. (all suitably covered to prevent contamination).

A useful list of items is included in Table 6.1 at the end of this Chapter.

6.4 Procedures to Minimise Contamination and Exposure

Many of the procedures used are similar to the isolation techniques used with other contaminants such as chemicals and bacteria; the same principles apply to radioactive contamination. All team members should be properly trained in the routine aspects of working with radioactive materials, i.e., carrying out procedures expeditiously, keeping well away from the patient when not working on him/her, using shielding whenever appropriate; using long-handled forceps to remove contaminated dressings, etc. For long, involved procedures, rotation of personnel is desirable if they are suitably qualified and experienced.

  - If the distance from the ambulance entry to the triage/treatment areas is large, a clean hospital trolley with a sheet on it should be taken to the ambulance and the patient lifted on to the sheet together, if necessary, with any sheets etc. on which he/she was lying in the ambulance. The trolley sheet should then be folded over the patient to contain any contamination and the patient taken into the controlled area.

- If the patient is already wrapped in a clean sheet or is on a backboard due to injuries, the "package" and backboard (when used) should be lifted onto the hospital trolley and subsequently transferred to the decontamination table.

- The ambulance officers should stay at the ambulance until they have undergone contamination monitoring, as it is possible that they have contamination on them or the soles of their shoes. However, if it is necessary for them to go into the hospital, they may need to put on overshoes. The ambulance should be checked for contamination before it leaves the entry area.

- In triage, gloves should be changed between examining each patient to prevent transfer of contamination between patients. If patients arrive before monitoring equipment is available, treatment should proceed on the basis of the patient's history, using the same procedures as used with somebody contaminated with pathogenic bacteria.

- Monitoring equipment should be checked for proper performance; natural background levels in the areas should be measured before the arrival of patients. Personal monitors should also be worn.

- Contaminated clothing on patients should be removed by cutting from the head to the feet and folding inside out as it is cut so that the inside of the clothing is on the outside (the inside is not so likely to be contaminated). In extreme emergency, clothing can be ripped, but this produces fragments that are likely to disperse in the area

- As decontamination proceeds, progressive reporting on the treatment results should be given so that a change in treatment can be made if necessary.

- Although contamination rarely becomes airborne during decontamination procedures, any draughts that could disperse contaminants should be prevented. This may mean alteration to or blocking the ventilation system.

- Any equipment, such as X-ray units and X-ray film cassettes should be covered in plastic when entering the controlled area and the plastic removed and the items checked on leaving the area.

- All entry to and exit from the controlled area should be strictly controlled.

- One member of the team should stand on the clean side of the barrier to hand in items as required and to check items and people leaving the area for contamination.

- All items leaving the controlled area should be checked for contamination. Samples going to pathology or for measurement should be in individual bags; these should be identified clearly as to contents, with some warning to the recipients on the need for care in handling in case the samples are contaminated. Some follow-up for disposal of the samples may be necessary.

- To remove protective clothing after the decontamination procedures have been completed, the following order should be observed -

    - outer gloves, mask and cap, aprons (if worn) and gowns, which should be folded inside out to avoid contaminating clothing worn underneath them. These items should be removed in the controlled area and placed in designated bins;

    - overshoes, one at a time, as each foot is placed over the controlled area boundary; and inner gloves, whilst leaning over into the controlled area. These and the overshoes should be placed in designated bins just inside the controlled area boundary.

- All team members, the patient and any others should be checked for contamination from head to foot, front and back after removal of protective clothing and drapes as they leave the controlled area.

- The ambulance officers and ambulance and equipment should be monitored before leaving the hospital and controlled area, as appropriate.

- As waste bins are filled, the plastic bags in them should be removed, double-bagged (if not already done) and taken out of the area.

- Upon completion, floor coverings and other coverings should be rolled up and placed in plastic bags for disposal. The entire area should then be thoroughly monitored.

- All waste materials should be disposed of in accordance with prescribed procedures.

- Reference was made earlier to the hospital being forewarned of the arrival of contaminated patients. This may not always be the case. In these cases, normal hospital routine is followed until the presence of contamination becomes apparent. At that stage, the above control procedures should be activated, even at the expense of delay in treatment of an existing injury (unless of a life- threatening nature). A thorough check for contamination of all areas and items where the patient has been and of every person who has had contact with that patient should be made and decontamination procedures instituted.

Table 6. 1 Preparing an Emergency Department for Care of Contaminated Patients

I Emergency department preparation

A. Rolls of 900-1000 mm wide brown wrapping paper (butcher paper) or square absorbent padding sufficient to cover the floor from the ambulance entrance to the decontamination room, as well as cover the entire floor of the decontamination room
B. Rolls of 50 mm wide masking tape to secure the floor covering, tape decontamination team's sleeves and cuffs, cover handles in the decontamination room, and make a "control line" at door to decontamination room
C. Rope to delineate route from ambulance entrance to decontamination room
D. "Caution - Radiation Area" signs to place on rope and on door to decontamination room

II Decontamination room

A. Decontamination table with waterproof cover, burn table, or other specially designed table
B. Three 20-litre containers for wash water
C. Three large waste containers lined with plastic bags
D. Various sizes of plastic bags for samples, clothes, etc.
E. Cotton-tipped applicators
F. Stoppered containers for swabs of contaminated areas
G. Small lead storage containers for holding radioactive foreign bodies removed from wounds – obtain from Nuclear Medicine or Radiotherapy Department
H. Chart with drawing of patient outline, front and back, for recording contaminated areas
I. Solutions or materials for decontamination:
   1. Sterile saline
   2. Sterile water
   3. Sodium hypochlorite or household bleach
   4. Povidone iodine solution or other surgical soap
   5. Abrasive soap
   6. Soft scrub brushes
   7. Mixture of one-half powdered detergent and one-half cornmeal, kept air-tight or refrigerated
   8. 3-percent hydrogen peroxide solution
   9. Shampoo
J. All necessary emergency medical supplies and equipment (suction, oxygen, airways, intubations, IV solutions, etc.)
K. Sheets, blankets, towels, and patient gowns

Table 6. 1 Preparing an Emergency Department for Care of Contaminated Patients (cont.)

III. Decontamination team

A. Scrub suits
B. Gowns
C. Surgical hoods
D. Masks
E. Surgical gloves of various sizes
F. Waterproof shoe covers
G. Film badges, TLD badges or QFEs
H. Dosimeters
I. Rubber or plastic aprons (lightweight, not lead-lined, X-ray type)
J. Masking tape or equivalent

IV. Radiation Safety Officer

A. G-M survey meters
B. Ionization chamber
C. Alpha detector (optional)
D. Extra batteries for survey meters
E. "Radioactive" labels or stickers to mark containers holding contaminated specimens or swabs
F. Wax or felt pens to mark labels

Source and permission to use: "Hospital emergency department management of radiation accidents" by R.C. Ricks. ORAU publication 224.

7.0 TREATMENT OF CONTAMINATED PATIENTS

Before treatments for decontamination of a patient are carried out, any life-threatening injuries or trauma must be attended to and the patient's condition stabilised. Decontamination of the patient then takes precedence over the treatment of other injuries unless the patient is in great pain or his/her condition is deteriorating rapidly.

The priority for carrying out decontamination procedures depends on

- the location and activity levels of the contamination on or in the body;
- the radionuclide(s) and the chemical form and particulate size (for inhalation) of the radioactive material involved;
- the time between deposition of the contamination on or in the body and when decontamination procedures are to commence; and
- any treatment carried out prior to admission to hospital.

Some of the above information may not be immediately available as it could be dependent on the results of monitoring and biological sample analysis. In those cases, worst-case situations should be assumed in determining the type of treatment to be undertaken. Delays should not be allowed whilst awaiting complete information.

Outlines of the procedures for removal of external and internal contamination from a patient are given below.

7.1 External Contamination

7.1.1 General Principles Applicable in Decontamination Procedures

Decontamination of wounds and orifices should be undertaken as a matter of priority after other life-saving procedures have been effected. In general, decontamination of intact skin should be left until wounds and orifices have been decontaminated and wounds dressed or closed up, but before treatment of other injuries is undertaken. However, decontamination of the hands, face and head may have to be carried out early if the contamination levels in these areas are high, so as to reduce the spread and intake of contamination.

The procedures given in *Chapter 6* for control of contamination in a hospital should be followed. These procedures cover the use of appropriate protective clothing, floor and other area covering and controls to prevent spread of contamination outside the working area, proper training of personnel involved, adequate supply of waste receptacles, etc. The procedures given in *Chapter 5* for monitoring and collection of biological samples, swabs, dressings, etc. for later analysis should be followed.

Areas surrounding contaminated regions of the body should be draped and taped to prevent spread of contamination to them; the drapes should be waterproof. Absorbent pads or towels should be used to absorb any traces of liquids. For irrigating liquids, runnels should be made in the draping material so that the liquids can be collected in trays, buckets, etc. All contaminated materials, including liquids, should be placed in waste receptacles as they are finished with so that proper disposal can be effected.

Decontamination usually involves several repeat procedures. After each procedure, drapes, absorbent pads and towels should be removed and placed in waste receptacles and then radiation monitoring of the area carried out to assess the success of the procedure. Clean draping, pads and towels should be put in place before the next procedure commences.

Complete decontamination can rarely be achieved. However, repeat procedures should be carried out until monitoring shows that no further reduction is being achieved by each repeat procedure or until the skin shows signs of damage or the condition of a wound is aggravated.

It is difficult to prescribe contamination levels that are "satisfactory" as such levels depend on the actual skin area involved. For intact areas of the skin, final decontamination may occur through sloughing of the outer skin cells, which could take 2-3 days in many skin areas and about 15 days in other areas; for wounds, final decontamination of the wound area can also occur when the scab detaches some time after the injury.

7.1.2 Intact Skin and Hair

Removal of contamination from intact skin is important, but not as urgent as from other areas unless it is extensive and there is a considerable risk of it being spread to others and to equipment. There may be some loose contamination on the skin and this could become dislodged and be easily inhaled, ingested or dispersed elsewhere. Accordingly, any loose contamination should be removed early by using a damp gauze pad. Radioactive material, if allowed to remain on intact skin for a long time may also diffuse through the skin and eventually enter the blood capillaries and then be transferred through the body.

Decontamination of intact skin should be made in the first place by washing, rinsing, blotting dry and monitoring for remaining contamination and repeating the process three or four times, if need be. For washing, lukewarm water with a mild soap should be used. If the water is too hot, it will cause cutaneous vasodilatation and this increases the absorption of contaminants through the skin. If using lukewarm water and mild soap is not successful, the process should be repeated using a mild detergent and subsequently with a stronger detergent such as a dilute solution of sodium hypochlorite (household bleach). Gentle cleaning should be attempted at first, but becoming more aggressive. Fresh wash cloths or sponges and solutions should be used for each process; these may even need to be replaced part way through the first process. If the skin becomes damaged or red and sore, cleaning should be discontinued. In this situation, it may be desirable to rest the skin for 3-4 hours before repeating the process to allow the skin to recover. It may even be necessary to cover the area with a lanolin- containing cream and an impervious dressing and resume the process on the following day.

Only the contaminated area should be cleaned, with cleaning starting at the periphery of the area, working inwards towards the centre. This prevents the spread of contaminants to other areas. The surrounding areas should be draped and taped with waterproof material to help prevent the spread of contaminants.

Techniques such as scrubbing, using strong soaps or abrasive agents, or applying and later removing adhesive tape to remove contaminants should not generally be used as they tend to remove the outer dead layers of the skin. This reduces the skin's protective ability, thereby resulting in increased absorption of contaminants through the skin. However, for rough calloused skin, such as on the knees and hands, a scrubbing brush with a cream may be needed and cleaning in these areas can be fairly aggressive.

Sometimes, occlusion techniques can be helpful in decontamination procedures. By placing the patient's hand, for example, inside a plastic bag or glove whilst other procedures are being undertaken, the spread of contaminants can be avoided. In addition, the outer layers of the skin become hydrated and this helps the contaminants to diffuse out of the skin. However, the plastic bag or glove can cause sweating which, in turn, allows for easy rediffusion back into the skin. Accordingly, a cotton glove or pad should be placed over the contaminated area, inside the plastic bag or glove, to absorb sweat and prevent rediffusion of contaminants into the skin.

Decontamination of hair can be difficult due to its electrostatic charge and oiliness, as these tend to retain contaminants. Hair should be shampooed several times, with the head deflected backwards over a basin to keep water from the eyes and ears. A hair dryer should be used to dry the hair. Clipping the hair short may be necessary, but the head should not be shaved, as this can result in small cuts and abrasions which are not easily seen and into which contamination can get. Hair clippings should be collected in a labelled plastic bag for subsequent analysis.

If near-whole body contamination occurs, showering several times may be desirable using a mild soap, with towel drying and monitoring in between. Washing should always start at the hair, working downwards. if the patient is in bed, the usual nursing procedures for washing patients should be followed.

7.1.3 Wounds

These may range from minor skin abrasions to deeper wounds and include punctures and lacerations in the skin. Slightly different techniques may be applied depending on the type of wound. In general, however, wounds can be decontaminated in the same manner as cleaning dirt, bacteria, etc. from them.

Minor skin abrasions and burns present considerable potential for absorption of contamination into-the body as the surface is often raw and bleeding. These can be cleaned with lukewarm water and gentle washing, followed by rinsing and blotting dry. Sterile water or saline solution can be used for this. Repeat cleaning following monitoring may be necessary. A detergent and, if necessary, a topical anaesthetic, such as lidocaine may be used. Any residue of the contamination will probably become incorporated in the scab to the wound and this will slough off in due course.

Deeper wounds should be opened up to facilitate cleaning. They can be cleaned in the same manner as abrasions, but a preferred method is to irrigate them using sterile water or saline solution. Irrigation with a little pressure behind the irrigation stream, repeated several times with blotting dry and monitoring between each application is usually successful. Lacerations may need greater pressure for irrigation. In some instances, however, free bleeding of the wound should be encouraged by occluding the venous return with a constriction band.

In the case of highly toxic contaminants such as plutonium or one of the long-lived α emitters, for which DTPA is an effective chelating agent (Appendix A6), treatment with DTPA should be commenced immediately and a DTPA solution used as an irrigating fluid. This will chelate the radioactive material and if it enters the blood stream, it will be excreted in the urine. For such contaminants, the use of a venous constriction band is particularly desirable.

Deep debridement and excision of a wound may even be necessary but only when particles or pieces of highly toxic material have been embedded in the tissues. However, this is an extreme action and should only be undertaken after full consideration of the long-term risks of not removing all the contaminant, the function of the region affected and the psychological effects on the patient of changed body appearances.

Small puncture wounds can be conveniently excised by a skin biopsy punch. Whenever any tissue is excised from the body, it should be placed in stoppered, labelled containers for later analysis.

After cleaning, wounds can be dressed, provided the contamination has been effectively removed. They can be closed up at that stage, but this could wait if there are other injuries requiring early attention.

As a precautionary measure, urine and possibly faecal samples should be collected for analysis if wounds are contaminated, to check on any uptake of contaminants from the wound into the body.

7.1.4 Body Orifices

Body orifices should be cleaned out as for any other contaminant. Such decontamination should be carried out quickly to reduce transfer into the body.

Gentle irrigation and suction of the mouth should be started promptly to reduce the amount of material reaching the stomach, with the mouth turned sideways or down (as the patient's condition allows) so that the irrigation solution runs out of the mouth and is not swallowed. Brushing of the teeth with toothpaste is also helpful as most toothpastes contain chelating agents. There should be frequent rinsing of the mouth using a 30% hydrogen peroxide solution, care being taken not to swallow any. After the mouth has been decontaminated, a nasogastric tube should be inserted into the stomach to determine if radioactive material is present. If so, treatment to limit uptake should be started and lavage instigated with normal saline solution in small aliquots so that the stomach contents are not forced through the pyloric sphincter.

For the nose, nasal douches can be used and for the ears, irrigation should suffice provided the tympanic membranes are intact. There should be frequent suction so that radioactive material is not forced deeper into these cavities. For these, draping, absorbent pads and towels should be used as for wounds.

Location of contamination around the eyes can be difficult as it may be in the eyes, eyebrows, eyelashes, eyelids or adjacent tissues. Normal cleaning techniques for these regions should be used, but the eyes themselves should be rinsed by directing a stream of water or saline from the inner canthus to the outer canthus so that material is not forced into the lacrimal duct. chemicals, detergents, soaps and bleaches should not be used near the eyes. Draping, pads and towels should be used as for wounds.

7.2. Internal Contamination

Internal contamination may arise from inhalation or ingestion of radioactive material as well as through absorption of radioactive material in wounds or by transfer from body orifices. Decontamination of wounds and body orifices is covered in the first part of this Chapter, but the contaminants from these regions may move into the blood stream before they can be removed. In these cases, the contaminants will be translocated to organs and tissues in the same manner as contaminants that are inhaled or ingested. Their removal is then the same as for inhaled and ingested contaminants.

Many radionuclides taken into the body have short effective half-lives (hours or a day or two) and do not present a significant hazard in regard to long-term effects unless the intake was large. In the latter case, and for radionuclides which have longer half-lives, there is a medical urgency to initiate treatment to reduce the deposition of radioactive contaminants in the body and to increase their rate of excretion from the body. The most important considerations in treatment are

- selection of the appropriate technique or drug for the particular radioactive material involved and its location in the body and
- its timely administration after the accident. Some treatments may need to be extended over a long period of time - weeks or months before they no longer achieve any further reduction of contamination in the body.

For most treatments, the risks and side effects in implementing a treatment are quite small, provided the treatment is appropriate for the particular radioactive material involved - much smaller than the risks arising by delays in implementation of treatment. Lung lavage and some treatments with limited drug reactions would be exceptions to this rule.

Decontamination of the body will be most effective if it can be implemented in the first hour or two after intake before contaminants enter the systemic circulation; however, in many cases this is not possible. Delays should not be allowed to occur because of lack of knowledge of the quantity of radioactive material taken into the body. Initial treatment should be implemented even if there is a suspicion of internal contamination and this should be based on the history of the accident and take into account any monitoring, particularly of body orifices, which might give some indication that a large intake could have been involved (see *Chapter 5*). A second treatment may even be desirable whilst waiting for realistic evaluation of the activity of material in the body.

Estimates of the activity of radioactive material taken into the body may not become available for some time (hours or days), but the treatment course can then be modified if necessary. As treatment proceeds, monitoring of biological samples from the patient should be undertaken, as this will give useful information on the effectiveness of the treatment and also indicate any need for changes. It can be discontinued when elimination of material from the body has been reduced to acceptably low values and continued treatment is only causing distress or great inconvenience to the patient.

In some instances, treatment must be given following an intake of radioactive material, not so much because of its radiotoxicity, but because of its chemical toxicity. The best example of this is uranium, where the radioactivity is only of concern if the amount in the body is thousands of times the prescribed body burden. On the other hand, if it is only several body burdens, the chemical toxicity of the uranium can result in a diminished function of the kidneys, simply due to the precipitation of uranium as a heavy metal in the system.

Decontamination techniques used will depend on the type of radioactive material involved and its location within the body (as well as on any other hazardous materials present and the patient's condition). In general, contamination in the gastrointestinal tract should be removed as quickly as possible. If it becomes absorbed in the gut, the aim is then to minimise its further absorption into regional lymph nodes and the general circulation. Uptake by the various organs can be reduced by the use of blocking agents, dilution techniques or chelating agents. Other action, such as lung lavage might be considered in certain situations. These possibilities are discussed below.

7.2.1 Clearance of Gastrointestinal Tract

Early action to remove material from the body may, in many cases, involve chemical manipulation in the gastrointestinal tract or hasten the passage of material through the body. Purgatives, such as magnesium sulphate, will shorten the intestinal transit time, thereby reducing absorption and radiation exposure to the gut wall and nearby tissues. Alkalising the stomach may cause the formation of relatively insoluble hydroxides or will, at least, keep the pH high enough to reduce the solubility of some salts. Metals such as copper, iron or plutonium are generally more available for later absorption after spending some time in the acid milieu of the stomach. With chromium, the opposite is true - in this case, acid gastric juice reduces hexavalent chromium to the poorly absorbed trivalent ion.

Aluminium containing antacids can be used for phosphorous, potassium and strontium; also, alginates for strontium and Prussian Blue for caesium, rubidium and thallium. The majority of preparations used for these treatments are non-prescription medications and are readily available; others, such as Prussian Blue may need prior approval.

Gastric lavage may be used for the evacuation of toxic materials from the stomach by means of a gastric or nasogastric tube. It might be used when there is a known intake of a large quantity of radioactive materials and the materials are still in the stomach. Water is pumped through the tube and then siphoned back until such time as the stomach washings are relatively free of radioactive material. Emetics to induce vomiting and thereby empty the stomach promptly might also be used. They are usually most effective when 200-300 ml of water are taken concomitantly, but should not be used if the state of consciousness is impaired or after the ingestion of corrosive agents or petroleum hydrocarbons.

7.2.2 Blocking Agents

A blocking agent is a chemical which saturates a tissue with a non-radioactive element, thereby reducing the uptake of the radionuclide. Large quantities of the agent are administered to achieve this, but the agents must be in a readily absorbable form. The most common example of this occurs with intakes of radioiodine where equilibrium between ^{131}I and body fluids is reached in about 30 minutes and approximately 30% of the intake is deposited in the thyroid. Administration of stable iodine in the form of potassium iodate or potassium iodide tablets will reduce uptake by the thyroid gland by about 90% if given in less than two hours after intake and by about 50% if in less than three hours. Stable strontium in the form of strontium lactate or strontium gluconate is useful as a blocking agent for radiostrontium.

7.2.3 Dilution Techniques

One dilution technique is referred to as isotope dilution where the administration of large quantities of the stable isotope of the radionuclide reduces (on a statistical basis) the opportunity for incorporation of atoms of the radionuclide. With this technique, it is desirable to get the stable isotope into the system quickly and, when possible, in a chemical form that is more easily absorbed and incorporated than the radionuclide. Tritium, for example, can be diluted considerably by the forced drinking of water (or other suitable fluids) 3 to 10 litres per day for a week will reduce the effective half-life of tritium in the body by more than 50%.

Another dilution technique is referred to as dilution therapy or displacement therapy, where a non-radioactive element of a different atomic number is used to compete with the radionuclide. Examples of this are the use of calcium or phosphate to compete with radiostrontium and stable iodine to reduce the uptake of radiotechnetium.

7.2.4 Chelating Agents

Chelating agents are used in routine everyday medical care for heavy metal poisonings and they have a place for treatment in some cases of intake of radioactive materials. Because they tend to find things in the blood or in the recycled phase from deposition sites, they can be used well after an accident has occurred days, weeks or even months. Chelators drive everything to the kidneys for excretion in the urine. Thus, it is important to establish adequate kidney function in patients who are given chelation therapy, otherwise the kidneys become another target organ and can receive quite a substantial radiation dose. However, they should not be used in the case of uranium intake as the kidneys can then be subject to uranium overload, with the consequent clinical toxicity.
Treatment is generally continued until it appears to be no longer achieving any results. Daily treatment may continue for a few months and if, after that time, there seems to be no further decrease in radioactivity in the urine, the treatment regime can be modified by less frequent administration until urinary excretion rates of the radionuclide, with and without treatment, are not significantly different; discontinuance of the treatment would then seem to be appropriate. The side effects of this type of therapy are limited and generally tolerable, but any discomfort to the patient must also be taken into account when considering changes to the course of treatment.

Chelators that can be used include -

- **EDTA (ethylenediaminetetraacetic acid).**

The calcium salt of this is the most common form for treating lead poisoning. It can also be used to chelate Zn, Cu, Cd, Cr, Mn and Ni and transuranics such as Pu and Am, but not Hg, As or Au. It does have side effects; in patients with preexisting renal disease, it should only be used with extreme caution.

- **Ca or Zn DTPA (diethylenetriaminepentaacetic acid).**

This is much more powerful than EDTA and is best used for transuranics, some rare earths (Ce, Y; La, Pm and Sc) as well as Zr and Ni. There are some indications that they might be useful for cobalt and perhaps for uranium contamination. The effectiveness is good for soluble salts, but almost nil for insoluble compounds. Whilst there have been some side effects with this agent, there have been no serious effects reported. Treatment can be given as lg intravenously in 250 ml isotonic solution or 5% dextrose in water. It may also be administered as an aerosol. If DTPA is not immediately available, EDTA can be used. (See Appendix A6 Information Material)

- **Dimercaprol (BAL).**

This is generally used for heavy metal poisoning and forms chelates with Hg, Pb, As, Au, Bi, Cr and Ni. Although seldom the agent of first choice, it is usually available in pharmacies, but it is toxic and should be used with care.

- **Penicillamine.**

This chelates with Cu, Fe, Hg, Pb, Au and possibly other heavy metals. It is preferred to dimercaprol and Ca EDTA for copper.

- **Deferoxamine (DFOA).**

This is normally used for iron storage disease and so can be used for iron; it has been found to be very effective for plutonium if administered promptly.

7.2.5 Lung Lavage

The principle involved in this technique is to remove highly insoluble material from the lung before it has time to become solubilised. In its insoluble form, the material could stay in the lung for a long period of time and result in very high doses to localised areas of the lung. In almost all cases, the effectiveness of lung lavage has come from sub-human experimentation; in the case of beagle dogs, the reduction due to lung lavage has been substantial. It might be considered appropriate to use it when individuals have been contaminated with insoluble material in the lung; the lung dose might then be reduced by 25% to 50%.

Lung lavage requires multiple procedures with sterile saline solution to be effective and may require general anaesthesia. The patient is effectively half drowned in the removal of material and fluid from the lung and it is extremely uncomfortable for him/her. In addition, the risks of general anaesthesia are probably higher than the risks from internal deposition. Optimally, lung lavage should be undertaken within three hours of an accident, but this is not always possible.

Lung lavage should only be considered if the particle size and the particle size distribution of inhaled material is known, as the distribution of dose in the lung is of prime importance. It is only appropriate if the amount inhaled is at least of the order of a few times the lung burden and the insoluble material is of a finely divided particle size, with small particle size distribution. In addition, the patient should be young (under the age of 30 years and preferably less than 25) and healthy and have a long life expectancy.

8.0 HOSPITAL PLANNING FOR MANAGEMENT OF RADIATION ACCIDENT PATIENTS

8.1 Formulation of Plans

Although the occurrence of radiation accidents is rare, hospitals need to give consideration to preparing plans for the management of patients *who* have been involved in them. This applies particularly to any hospitals designated to manage such patients. In these days of great public concern and fear of radiation and exposure to it, knowledge of the existence of a plan for the proper medical management of such patients can be very reassuring. The plans may differ in detail according to the type of accident, but the general principles applicable are common to patients from many types of accident.

When a radiation accident occurs in the workplace, individuals may or may not be immediately aware of its occurrence. If not immediately noted, it is highly likely they will know of it reasonably soon afterwards due to the implementation of controls, monitoring procedures etc. However if a radiation accident involves members of the public it is unlikely that they would be aware of their irradiation immediately. They may only become aware if profound ill effects arise later and even then, these may not be recognised as the effects to radiation. On the other hand, members of the general public may suspect they have been affected by radiation or radioactive material if they have been in the vicinity of a radiation incident and present for medical assessment even though they are not injured, just to check whether they have become contaminated with radioactive material.

Accordingly, individuals *who* have been involved in radiation accidents may arrive at a hospital for treatment with or without prior notification. In either case, the treatment procedures are the same. If, however, the individual arrives without notification and it is not recognised for some time that radioactive contamination was involved, there could be spread of contamination within the hospital. Once contamination is found or suspected, the controls used for such a situation should be put in place (see Chapter 6). There will then be a need to be a check of the hospital areas, equipment and personnel with which the individual had been in contact and decontamination carried out, if they are found to be contaminated.

The plans can be divided into two situations - one would cope for accidents involving external exposure and the other radioactive contamination. Both situations may arise in an accident, but treatment for radioactive contamination would be undertaken first.

8.2 Planning for Externally Exposed Patients

If exposure to external sources of radiation only was involved and there was no possibility of radioactive contamination, patients should proceed through the accident and emergency department in the normal manner, after any necessary stabilisation of their condition. There is no hazard to hospital personnel from such patients ~ they are no different to patients who have suffered local or extensive thermal burns in that regard.

With most of these patients, there may not be any symptoms or symptoms may not arise for a few days or weeks; for others, immediate effects may be anorexia, nausea, vomiting, etc. , which will require some medication. Measures to minimise infection will have to be put in place and some blood analyses will be needed as changes in blood counts can indicate an appropriate course of treatment and cytogenetic studies may be used to assess the doses. These are covered in Chapter 3. There is, therefore, no need for the preparation of detailed plans to deal with these patients. However, a list should be prepared of specialists who can be contacted to give prompt advice on the initial action and subsequent treatment for the symptoms arising.

8.3 Planning for Contaminated Patients

If radioactive contamination occurred in an accident, it is possible that contamination might be spread within the hospital and personnel and equipment could become contaminated. Accordingly, measures have to be adopted to prevent or minimise this and plans must be in place within the hospital to cope with this potential situation.

The elements of planning for the management of radiation accident patients are similar to those for other types of emergencies - i.e. , for hazardous chemicals, earthquakes, major fires, floods, etc. Many of the precautions involved would be similar in principle to those for hazardous chemicals and bacteria. If it is thought that planning for the management of contaminated patients is unique, then confusion on procedures to be adopted may occur and any problems will be compounded. If the planning takes into account concepts used in other emergency situations, the hospital personnel will be much more comfortable with the procedures to be followed and will be less likely to make mistakes.

The elements of planning should take into account the following -

- potential accidents in the area served by the hospital. These should be based on the various facilities in the area using radiation sources and radioactive material and on the types of accidents with which they could be involved. Such facilities include nuclear medicine departments, in which β and γ emitters of relatively short half-life are generally used, scientific laboratories where all types of radioactive materials are used, mainly in small quantities, nuclear facilities where there is a greater possibility of accidents involving transuranic and α emitting material than in other facilities. Accidents could also happen elsewhere, but the treatment procedures and techniques used would not differ significantly from those on which plans are formulated;

- the emergency response team - its composition, qualifications, experience, responsibilities and duties of members and any special training requirements;

- the hospital facilities, equipment, resources and supplies available for each type of situation '(much larger quantities of resources and supplies will often be required than for other emergencies);

- the need for radiological monitoring and medical examination upon arrival of the patient, to allow for early decisions on the treatment course;

- the need for controlling access to and exit from prescribed areas;
- the need for storage areas for contaminated items prior to disposal;
- the provision of emergency power and computer back-up
- the arrival of patients without forewarning;
- the need for dealing with a large number of patients, some of whom may not be contaminated or injured and some of whom may have multiple injuries as well as being contaminated;
- the possibility that initial triage of patients might be better carried out at the scene of the accident when a large number is involved so that uninjured patients can be managed away from the hospital;
- the need for separate entrance and triage areas for large numbers of patients who are contaminated and have other injuries;
- arrangements with nearby facilities for showering and decontaminating large numbers of contaminated but uninjured patients;
- the need to carry on with the normal routine functions of the hospital with minimum interruption (i.e. , normal and severe injuries, cardiac cases, obstetric cases and so on);
- communication (a) within the hospital, (b) with suppliers to the hospital, (c) with ambulance officers and those at the scene of the accident, (d) with relatives of the patients and (e) with the media, if need be;
- the ongoing staff training programs;
- testing of the plans;

- and agreements and/or arrangements made, or that need to be made, with local, national or overseas organisations, as well as with other nearby hospitals, in regard to assistance, supplies, travel, funding etc.

- The plan should be put into effect as soon as advice is received that a radiation accident victim is to be admitted. It should indicate:

- the administrative procedures in place for managing patients whilst allowing other hospital procedures to function unimpeded;

- the names of the emergency response team members (and their alternates) and their contact ("beeper") numbers, their responsibilities and functions;

- the person(s) to be informed immediately upon receiving advice of an arriving patient;

- the names of specialists, such as radiation oncologists, nuclear medicine physicians, haematologists, pathologists and the radiation control authorities and of other organisations that can be of assistance;

- the entry, triage and treatment areas. These may vary, depending on the number of patients involved, but must be large enough for the hospital staff needed for the situation as well as for trolleys, stretchers, etc. They should be away from main traffic areas of the hospital, but close enough to diagnostic and life saving facilities in case they are needed,

- the quantities of linen, towels, plastic bags, protective clothing (of sizes to fit different team members), drapes, floor coverings, body charts, special medical supplies needed per patient or for groups of patients;

- items to be moved out of the treatment areas;

- monitoring arrangements for patients, ambulance, ambulance officers, staff, etc;

- proper working procedures;
- records to be kept;
- provision of emergency power, computer back-up and telephone facilities;
- security arrangements for the areas and for oversight of all persons admitted from the accident; and
- communication proposals, including contact with relatives and the media and advising the hospital administration when a patient arrives so that they can direct incoming enquiries appropriately and consider organising other hospital activities, if need be.

The plan should be prepared as a collaborative effort by all members of the response team. It should include details of procedures to be followed in a clear and concise form so that there are no problems in following it. Each team member should be familiar with it and have a readily accessible copy of jobs he/she has to do and the. resources for which he/she has responsibility; these should be given in detail, not in generalities. This is particularly important as, in an emergency, the usual routines can be upset and certain activities must take priority over others.

The plan should be kept up to date with regard to staff changes and new information on procedures to be followed.

8.4 Emergency Response Team

A suggested emergency response team, together with the responsibilities of each member of the team are given in Table 8.1 at the end of this Chapter. The need for all persons in a team to be present for a single patient may be determined by the particular circumstances when an accident is reported. In some cases, whilst team members have responsibilities, some of their functions may be undertaken by other members if they are not present at the time.

Consideration might be given to the team coordinator or team leader being somebody other than the emergency physician as he/she will be fully devoted to the medical care of the patient(s) and will not have time to ensure that all other activities are under control and coordinated. It must be remembered that, in these situations, team members have to concentrate very much on every step they take so that contamination is not unwittingly spread further. The coordinator needs to have a good grasp of the procedures necessary and the problems likely to arise and be able to make decisions, after consultation with others, which will lead to the best outcome of the whole exercise.

The success of the procedures will depend on the individual team members and their collaboration. Each team member, as well as carrying out the duties for the particular exercise, has a responsibility to ensure that all equipment and supplies relating to his/her own activities are available and in place prior to the patient arriving.

Once the emergency is over, team members should analyse the procedures critically to determine how the plan, etc. might be modified in case there is another accident.

Table 8.1 Emergency Response Team	
Team Member	**Responsibility**
Team leader	Lead, advise and coordinate.
Emergency physician	Diagnose, treat and provide emergency medical care (can also function as team coordinator or triage officer).
Triage officer	Perform triage, based on symptoms, monitoring and obtain history of the accident.
Nurse	Assist physician with medical procedures, collection of specimens and decontamination of the patient; assess patient's needs and intervene appropriately.
Technical recorder	Record and document medical and radiological data.
Radiation physicist	Radiation monitoring of patient, staff and areas, ambulance, etc.; advise on contamination and exposure control; maintain monitors; manage contaminated wastes and other contamination control mechanisms.
Media officer	Release accident information to public media.
Administrator	Coordinate hospital response; assure normal hospital operations.
Security personnel	Secure the controlled and ambulance areas; control access to and exit from areas.
Maintenance personnel	Aid in preparation of the controlled areas for contamination control; provide various supplies.
Laboratory technician	Provide routine clinical analysis of biological samples.
Counsellor	Counsel patients and relatives.

Source and permission to use: "Hospital emergency department management of radiation accidents" by R.C. Ricks. ORAU Publication No. 224.

8.5 Testing of the Plans

No matter how well plans are drawn up, they are useless unless all members of the team and others in the hospital who might be involved in an emergency do not practise what is set out in the plan. The complete plan should be tested periodically - at least once a year. Often scenarios can be devised to test each component of the plan and these tests can be spread throughout the year and repeated several times where appropriate. Tests should be carried out unannounced, as this is the best way of highlighting problems that might arise in a real emergency. Periodic tests also result in team members having more confidence in managing a situation, should it eventuate. In addition, it enables team members to assist or advise others in different locations on various procedures and techniques.

When carrying out a series of tests, the "emergency" should include situations where the "patient" needs life-saving procedures or suffers from shock, fractures or wounds as well as being contaminated. This will assist all team members to perceive the proper priorities in managing a patient. The tests should be used to check whether information is transferred to and between team members satisfactorily. They also enable members to become familiar with different techniques and equipment. For example, a nurse should be able to use a contamination monitor to show decreases in contamination levels, but not be expected to assess the readings meaningfully. Wearing two pairs of gloves may be difficult in some situations and practice helps considerably here. Techniques for removing contaminated clothing from "patients" and protective clothing from members should also be practised. The tests should also indicate the adequacy or otherwise of supplies.

Testing of the plan is best carried out with people who can act the part of patients very well. They need to be uninhibited type individuals, and not object to clothing being removed, "medical" treatment and non-invasive techniques. They should have a good knowledge of radiation effects and medical procedures, as this helps in making the exercise more realistic e.g., when to feel nauseated, vomit, etc. for a large radiation dose or how a patient exposed to radiation or contamination might react, concern about immediate family, etc. Such realism helps the team members manage in a more professional manner.

Radioactive materials, if used, assist in making tests more realistic, but caution is required in this regard as exposure of the "patient" or team members should be kept minimal. In addition, they should be warned if radioactive materials are being used. Quite often, fluorescent material with the aid of a black light can be used to practise control and/or demonstrate spread of contaminants - this is very helpful when clothing is being removed and folded. Moulages can be made and placed on the "patient's" skin to simulate wounds and these can have low activity, short half-life material incorporated in them (but radiation levels through the back of them should be checked). Alternatively, an inanimate manikin can be used and low activity, short half-life material placed on this and its clothes for testing decontamination procedures. Team members, in their protective clothing and in their subsequent disrobing, should not get any contamination on them in this type of exercise.

Not only does testing the plan serve as a refresher to team members of the procedures involved in an emergency, it serves as a useful training experience for new members of the team and of alternates. It is helpful to others who might be involved in the hospital because staff turnover might be higher in some of these areas. After each test, whether it is the complete plan or components of it, a review and critique should be made to determine difficulties and where improvements can be made. This should be done shortly after and certainly within 24 hours of each test.

9.0 COUNSELLING AND COMMUNICATION

People involved in a radiation accident will be concerned for a very long time after the accident about the consequences of their exposure to radiation or radioactive contamination. This arises from the general fear prevailing in the community about radiation; this fear is based mainly on incorrect perceptions about radiation effects. People are generally aware that radiation can induce cancer and that it may not become manifest until many years after exposure; however, when they themselves are exposed to radiation or contamination, no matter how small, they can become certain that they will get cancer or some other severe illness. Later on, if any illness eventuates, no matter what the illness, they may blame the radiation they received at the time of the accident.

If an accident results in local radiation injury, there may be considerable pain shortly after the accident, as well as a long time afterwards when the injury has apparently healed. There may also be concern about possible disfigurement of the body.

If an accident results in radioactive contamination being present in or on the body, there can be a sense of isolation because the patient and others with whom he/she comes in contact feel that radioactive contamination is transferable. This can lead to denial, anger, depression, loss of control and so on. In addition, there will often be an expectation by the patient that all contamination will be removed from the body and there could be great psychological problems when he/she finds out that this cannot be accomplished. There could be lingering worries about effects arising from any contamination left in the body or even from radioactivity that was in the body but which had been removed.

After completion of treatment, there can be concerns about procreation, whether treatment leads to complete recovery or not and even about the possibility of death. Later, hypervigilance may develop on the part of the patient regarding any illness arising after the accident and this may also result in illnesses that are psychosomatic in nature. For the above reasons, counselling of the patient should commence immediately after treatment so that the patient can understand the consequences of his/her radiation involvement. It is essential that these things be put into proper perspective. Considerable reassurance of the patient may also be desirable in the early stages of treatment to assist in obtaining good cooperation throughout the treatment. The patient should certainly be kept informed during the course of treatment of his/her response to the treatment and of the prognosis.

The patient's relatives may also need counselling as they could be worried about the patient's future health, how best to manage him/her and the possibility that they might become radioactive. This counselling should also commence at an early stage after an accident.

Some hospital staff may need counselling after an accident. Although they may have learnt about radiation effects in their training, their reaction may be different when faced with an actual situation. In addition, there may be some staff present during a treatment who are not used to working in an accident and emergency department and they may be upset at some of the things they see. Reaction to these sights may persist for a very long time after an accident and this may be worse if a friend or colleague is involved. Counselling may therefore be necessary, not from the point of view of radiation, but because of the sight of injured patients. This may be the case particularly if there are several patients injured in an accident.

When a large-scale accident exposes many people to radiation or radioactive contamination, good communication is essential and recourse must be made to the radio and television networks. Carefully prepared information and instructions, if need be, must be given as soon after the accident as possible and at frequent intervals. In these accidents, people may need to remain in shelter for a limited time or be evacuated. Whilst there is a perception that panic occurs in these situations, experience has shown that this is not the case. People will naturally be concerned for their families and friends and be anxious to be reunited with them (almost immediately), but protective action can be carried out in a controlled and orderly fashion provided that adequate explanation is given on what is happening and any order of priority. Panic is more likely to set in later when there has been time for the immediate protective action to be completed and people begin to worry about the future and possible health effects of radiation exposure. Whilst counselling cannot be carried out en masse in these situations, there will be a need for some individual counselling to be given. It is probably not very different to earthquake, fire and flood situations except for the fear of later radiation-induced effects.

At the time of any emergency which affects a large section of the public, hospital staff who must remain on duty will also be concerned about relatives and friends who may be at or near the accident area. Their ability to respond effectively to patients may be undermined if they are not totally absorbed in caring for them. Patients themselves may also be worried about relatives and friends. Accordingly, it could be helpful if details of the accident and the environment and protective procedures adopted could be made available, possibly through the hospital intercommunication or paging system.

In the event of widespread radioactive contamination, there will be concern about food, water, playing areas, etc. Tests should indicate the safety or otherwise of such things. If food and water are at a safe level for consumption, it is important that there be demonstration of this by those who proclaim them to be safe, by consuming or using the items. If they are not safe, they should be clearly identified as such. A vital part of good public relations and allaying anxiety is the setting of examples, demonstrating to people that things are safe.

Fear and anxiety amongst the general public in a major radiation accident can be reduced significantly through accurate and helpful media reports. To this end, a good liaison with the media should be developed. This, in itself, involves an understanding of what the media does and how it operates. The media is commonly briefed through the organisation responsible for controlling the situation but that organisation should be given the correct information by someone who is familiar with all the facts. In many cases, the Police have the responsibility for coordinating resources required by combating authorities, activating support agencies, controlling movement of people and vehicles and coordinating the provision of information to the media and the public. In smaller accident situations, media liaison may be through the hospital, radiation control authorities or other organisations, depending on the scene and type of accident.

Once an accident happens, reporters will appear seeking information on the cause of the accident, its details and the consequences. They will seek information from anyone willing to give it and, accordingly it is essential that a spokesperson be appointed to be the sole person to deal with the media. If more than one person deals with the media, it is possible that different and conflicting information could be given, with the result that the public could become confused and worried.

The spokesperson must be a person who is knowledgeable about the topic - accident scenarios, radiation effects and treatments. He/she should be chosen in the stages of planning for management of accident situations and patients. He/she must be fluent and at ease in dealing with the media and be totally honest in all statements. Credibility is a very important factor in dealing with the media. It is essential that factual information be given in a clear and simple form so that it is easily understood by the public. Speaking slowly at interview helps in this regard and enables accurate copy to be made and the audience to easily understand the words. Short sentences are much more helpful than long, rambling sentences. Short sentences can also be used in their entirety and can form separate title quotations. The main issue should be identified and the information given confined to that issue as much as possible. Technical jargon must be avoided, as this only confuses the issue, can lead to misquoting or misinterpretation and makes the information less understandable. Although the spokesperson is talking directly to a reporter, he/she is ultimately talking to the general public and it is not appropriate to go into details of technical aspects of accidents.

Within a hospital, the spokesperson should be located well away from the triage and treatment areas so that there is no interruption to the medical management of patients. On no account would cameras, for example, be allowed into those areas as there would be the risk of them becoming contaminated with radioactive material. A separate telephone line for the spokesperson would be helpful and the media should be given this number in preference to the hospital switchboard number. These actions should assist in creating a helpful climate in interactions with the media - interviewing them in a busy passage is most unhelpful and likely to lead to incorrect information being given out.

As a general rule, the media needs information immediately as there are deadlines to be met - both for newspapers and television. The temptation to "ring back" should be avoided. If the deadlines cannot be met, the media will go elsewhere for its information, which may be incorrect and it might indicate that the spokesperson was unwilling to comment or was not available. Invariably, the information will be edited to fit into the space or time available and this may result in incorrect or misleading information being issued. If possible and time permitting, the media should be asked to read back to the spokesman the news item to be issued so that any corrections can be indicated.

One of the best methods of informing the public is through radio interviews or talkbacks. By going straight to air, simple, clear and unedited information can be given to the public. Quite often a news release can also be given to the media by the issue of fax messages to all sources. These can be prepared carefully and may often be used in their entirety. By this means all media sources receive exactly the same information for reporting.

In controversial subjects such as radiation, it can be useful to create goodwill with a few experienced journalists by discussing various aspects of the subject with them in a "quiet" time so that if news does eventuate, some credibility and background information will have already been established.

One other means of communication involves the telephone system when an accident or unusual event occurs. It is easy for the switchboard to become totally blocked at that time and people cannot communicate either into or out of a hospital. The latter, in turn, may make continuation of treatment difficult if, for example, an urgent need for supplies arises. Consideration should be given to this in planning for the management of accidents and patients. Separate telephone lines may be necessary, particularly for urgent outgoing calls. Reference was made earlier to a separate line for use with the media. As part of their role in coordinating information to the public, the Police may set up an emergency advice line when an emergency could last some time. This gives out prerecorded messages, with the contact number being given on radio and television.

See Parts 2 and 3 for

Section 2 and Appendices