



सत्यमेव जयते

Ministry of Health & Family Welfare  
Government of India

---

## Medical Management of Radiological and Nuclear Emergencies

---

Training Module

**Disaster Management Cell**  
**Ministry of Health and Family Welfare**  
**Govt. of India**



### Note

- The Department of Atomic Energy (DAE) maintains 24×7 operational Emergency Control Rooms to serve as the national contact point for any radiological or nuclear emergency. The primary and alternate control rooms, along with their contact details, are listed below for immediate reference:
  
- **Primary Emergency Control Room – Anushakti Bhavan, C.S.M. Marg, Mumbai (PIN 400001)**
  - Phone (24×7): **022-22023978/022-22021714/022-25505300/022-22862595/022-22862582 /09969201364**
  - Fax: **022-22830441**
  - Email: **daeecr@dae.gov.in**
  
- **Alternate Emergency Control Room – VS Bhavan, Anushakti Nagar, Mumbai (PIN 400094)**
  - Phone (24×7): **022-25991070 / 022-25991071 / 09969201365**
  - Fax: **022-25991080 / 022-25593080 / 022-25515283**
  - Email: **vsbecr@npcil.co.in**
  
- These contact points are operational round-the-clock to ensure rapid communication, coordination, and reporting in case of any radiological or nuclear incident. All stakeholders, healthcare professionals, and emergency response personnel are advised to use these contacts for urgent assistance or guidance.
  
- MHA Control Room: **011-2202309563/0112309356**
  
- NDRF Control Room: **011-26107953**
  
- **Also, inform the concerned District Magistrate.**



पुण्य सलिला श्रीवास्तव, भा.प्र.से.  
सचिव

**PUNYA SALILA SRIVASTAVA, IAS**  
Secretary



भारत सरकार  
स्वास्थ्य एवं परिवार कल्याण विभाग  
स्वास्थ्य एवं परिवार कल्याण मंत्रालय  
Government of India  
Department of Health and Family Welfare  
Ministry of Health and Family Welfare



### Message

The growing use of radiation in healthcare, industry, energy, and research underscores its value to modern society. At the same time, it necessitates constant vigilance and preparedness for potential radiological and nuclear emergencies. Ensuring the safety and health of our citizens in such situations requires not only robust systems and infrastructure but also trained and capable healthcare professionals who can respond swiftly and effectively.

While as per the National Disaster Management Plan (2019), the Department of Atomic Energy has been identified as the Nodal Department for managing nuclear and radiological emergencies, Ministry of Health and Family Welfare has been mandated with capacity development of healthcare functionaries on various aspects of medical management of radiological events.

Accordingly, this Ministry, under its Central Sector Scheme, 'Health Sector Disaster Preparedness and Response Scheme', has been undertaking capacity building in this critical domain. This training module on "Medical Management of Radiological and Nuclear Emergencies," has been updated by this Ministry in collaboration with experts drawn from the Nuclear Power Corporation of India Ltd., All India Institute of Medical Sciences (New Delhi), Safdarjung Hospital (New Delhi), Bhabha Atomic Research Center, National Disaster Management Authority, National Disaster Response Force, Institute of Nuclear Medicine & Allied Sciences, Defence Research and Development Organization, National Institute of Mental Health and Neurosciences and officials from Points of Entry. This update to the training curriculum and module represents a significant milestone in building resilience against medical management of radiological-nuclear emergencies. It also incorporates the latest guidelines from the International Atomic Energy Agency, the World Health Organization, and India's Atomic Energy Regulatory Board. It is designed to equip doctors and healthcare providers with the knowledge and skills to manage radio-nuclear emergencies, conduct effective triage, and integrate with broader disaster response mechanisms, in line with the National Disaster Management Plan.

I commend the Nuclear Power Corporation of India Ltd. and all contributing experts for their dedicated effort in developing this module. I am confident that it will serve as a valuable resource in advancing our national capabilities in medical management of radiological and nuclear emergency preparedness.

*Punya Salila*  
(Punya Salila Srivastava)

#StopObesity

टीबी हारेगा देश जीतेगा / TB Harega Desh Jeetega

Room No. 11102, 'C' Wing, Kartavya Bhawan-1, New Delhi-110001  
Tele.: (O) 011-24013601, 24013602, E-mail: secyhfw@nic.in

वंदना जैन  
संयुक्त सचिव  
**Vandana Jain**  
Joint Secretary



भारत सरकार  
स्वास्थ्य एवं परिवार कल्याण मंत्रालय  
कर्तव्य भवन-1, नई दिल्ली-110001  
Government of India  
Ministry of Health & Family Welfare  
Kartavya Bhawan-1, New Delhi-110001



### Foreword

Managing radiological and nuclear emergencies poses unique challenges for healthcare providers. Unlike conventional disasters, the hazards posed by radioactive materials are imperceptible and thus are accompanied by fear and uncertainty in the affected population. In such situations, the role of trained doctors and medical teams becomes critical—not only in providing clinical care but also in coordinating with other response agencies while reassuring the affected communities.

This training module on “Medical Management of Radiological and Nuclear Emergencies” has been updated to address these needs through a skill-based, practical approach. It integrates international best practices from the IAEA and WHO with national guidelines of the AERB, while drawing upon lessons from past incidents such as the Mayapuri (India), Goiânia (Brazil) and Samut Prakan (Thailand) incidents, where general communities have inadvertently been exposed to radio-nuclear hazards.

The module emphasizes hands-on training, case studies, tabletop exercises, and practical demonstrations. Participants will gain familiarity with triage, decontamination, use of personal protective equipment (PPE), and the medical management of acute radiation syndrome (ARS) and cutaneous radiation injuries.

Our experience over nearly a decade of conducting this program shows that healthcare professionals across India are eager to strengthen their preparedness in this specialized field. It is my hope that this revised edition will further support doctors and first responders in developing the confidence and competence required to respond effectively to radio-nuclear emergencies.

I extend my sincere appreciation to the Disaster Management Cell of the Ministry experts from Nuclear Power Corporation of India Ltd., Mumbai; All India Institute of Medical Sciences, New Delhi; Safdarjung Hospital, New Delhi; Bhabha Atomic Research Center, Mumbai; National Disaster Management Authority, New Delhi; National Disaster Response Force, New Delhi; Institute of Nuclear Medicine & Allied Sciences of Defence Research and Development Organization, New Delhi; National Institute of Mental Health and Neurosciences, Bengaluru and officials from Points of Entry, for their collaboration and dedication in preparing this training resource.

  
Vandana Jain

Room No. 11037, 'A' Wing, Kartavya Bhawan-1, New Delhi-110001  
Tel.: 011-24013629, 24013630, E-mail: vandana.jain@nic.in



न्यूक्लियर पावर कॉर्पोरेशन ऑफ इंडिया लिमिटेड  
(भारत सरकार का उद्यम)  
**NUCLEAR POWER CORPORATION OF INDIA LIMITED**  
(A Government of India Enterprise)

मानव संसाधन निदेशालय Directorate of Human Resource (Medical Division)  
नाभिकीय ऊर्जा भवन, अणुशक्तिनगर,  
Nabikiya Urja Bhavan, Anushaktinagar, मुंबई-400 094  
Website : [www.npcil.nic.in](http://www.npcil.nic.in)



**Message from Nuclear Power Corporation of India Ltd. (NPCIL)**

Radiation and nuclear emergencies, though very rare, pose significant challenges to public health systems due to their complex medical, environmental, and psychosocial implications. Preparedness for such emergencies requires a coordinated and informed medical response to mitigate health consequences and ensure the safety of responders, patients, and the public.

In this context, Disaster Management Cell, MoHFW, GoI, in collaboration with Nuclear Power Corporation of India Ltd. (NPCIL, Department of Atomic Energy) has developed a comprehensive Training Module on the Medical Management of Radiological and Nuclear Emergencies. The module aims to strengthen the capacity of medical officers and healthcare providers at various levels to respond effectively to radiological and nuclear incidents in coordination with national and local response agencies.

The updated version of this training module has been revised based on recent guidelines and technical inputs from national and international authorities, including the International Atomic Energy Agency (IAEA), World Health Organization (WHO), Atomic Energy Regulatory Board (AERB), and Bhabha Atomic Research Centre (BARC). It integrates lessons learned from previous national training programmes and incorporates the latest scientific and operational developments in radiation emergency medical management.

This document, along with the accompanying PowerPoint presentations, is intended to serve as a standardized reference for trainers and participants involved in capacity-building initiatives on radiological and nuclear emergency medical management across India.

Dr. Jyoti Purandare

**Chief Medical Superintendent**

**NPCIL - Mumbai HQ.**



**Dr. Pradeep Khasnobis**

Deputy Director General,  
Technical Support Unit, Disaster Management Cell  
e-mail : pradeep.khasnobis@gov.in



सत्यमेव जयते



आज़ादी का  
अमृत महोत्सव

भारत सरकार  
स्वास्थ्य एवं परिवार कल्याण मंत्रालय  
निर्माण भवन, नई दिल्ली-११००११

GOVERNMENT OF INDIA  
MINISTRY OF HEALTH & FAMILY WELFARE  
NIRMAN BHAVAN, NEW DELHI-110011



### Acknowledgement

This capacity-building course on “Medical Management of Radiological and Nuclear Emergencies” through a skill-based training of doctors has been developed under the Health Sector Disaster Preparedness and Response Scheme (HSDPR), a Central Sector initiative of the Disaster Management Cell (DM Cell), Ministry of Health and Family Welfare (MoHFW), Government of India, in consultation with experts from Nuclear Power Corporation of India Ltd., Department of Atomic Energy (NPCIL,DAE), All India Institute of Medical Sciences, New Delhi (AIIMS, New Delhi), Safdarjung Hospital (New Delhi), Bhabha Atomic Research Center (BARC), National Disaster Management Authority, National Disaster Response Force, Institute of Nuclear Medicine & Allied Sciences, Defence Research and Development Organization (INMAS,DRDO), National Institute of Mental Health and Neurosciences (NIMHANS) and officials from points of entry.

This initiative, with NPCIL has emerged as a flagship effort in strengthening India’s preparedness and response to radiological and nuclear emergencies. Over nearly a decade of successful implementation, the program has endeavored to empower healthcare professionals across the country to respond effectively to such complex, high-impact public health emergencies.

This document represents an updated and revised version of the training module, incorporating the latest guidelines, best practices, and lessons learnt from national and international experience provided by the International Atomic Energy Agency (IAEA), the World Health Organization (WHO), the Atomic Energy Regulatory Board (AERB), and the Bhabha Atomic Research Centre (BARC). Their frameworks, safety standards, and training resources have been invaluable in shaping the content of this module.

It stands as a testament to the collaborative spirit and unwavering dedication of experts and institutions from the fields of radiological and nuclear safety and emergency management. We extend our heartfelt gratitude to all who have contributed to this endeavor.

We sincerely value the leadership and guidance of Smt. Punya Salila Srivastava, Secretary, MoHFW and Smt. Vandana Jain, Joint Secretary (Public Health), MoHFW, which has been instrumental in guiding the development and institutionalization of this program.

The Disaster Management Cell acknowledges and deeply appreciates the contributions made by all the experts, throughout the development and piloting of the updated training that has ensured that this capacity building initiative remains practical, relevant, and aligned with national priorities.

**Dr. Pradeep Khasnobis**

### **Objective of the training program:**

The primary objective of this capacity-building program on *Medical Management of Radiological and Nuclear Emergencies* is to strengthen the knowledge, skills, and preparedness of healthcare professionals to respond effectively to radiological and nuclear incidents. Specifically, the training aims to:

- **Enhance awareness** of the health risks and medical consequences of radiation exposure among doctors and healthcare providers.
- **Build competency** in triage, diagnosis, and medical management of radiation injuries and acute radiation syndrome.
- **Familiarize participants** with national and international guidelines (IAEA, WHO, AERB, BARC) on radiation emergency response.
- **Develop skills** for using personal protective equipment (PPE), decontamination methods, and radiation monitoring devices.
- **Strengthen coordination** between medical teams, hospital administration, nuclear facilities, and disaster management authorities during emergencies.
- **Promote a safety culture** in handling radiological and nuclear emergencies through case studies, simulations, and hands-on training.

### **Duration of the training course: 4 Days**

When citing this document, the following citation should be used:

#### **“Medical Management of Radiological and Nuclear Emergencies - Training Module”**

A publication by Disaster Management Cell, Ministry of Health and Family Welfare, Government of India in consultation with Nuclear Power Corporation of India Ltd. (NPCIL, Department of Atomic Energy), Bhabha Atomic Research Center (DAE), National Disaster Management Authority, National Disaster Response Force and Institute of Nuclear Medicine & Allied Sciences (DRDO).

January 2026, Nirman Bhawan, New Delhi

## Table of Content

S.No.	Chapter No.	Topic	Page No.
1.		Training Schedule	
2.		List of Abbreviations	
3.	<b>1</b>	Introduction to Radiation	
4.	<b>2</b>	Fundamentals of Radioactivity	
5.	<b>3</b>	Biological Effects of Ionizing Radiation	
6.	<b>4</b>	Overview of Radio-Nuclear Emergencies: Radiation Accidents in Nuclear Power Plants - Experiences from the Past	
7.	<b>5</b>	Disaster Management: An overview (Radio-nuclear emergencies)	
8.	<b>6</b>	Radiation Therapy and Industrial Radiography	
9.	<b>8</b>	Orphan sources and RDD/ dirty bomb	
10.	<b>9</b>	Long Term Effects of Radiation	
11.	<b>11</b>	External Contamination: Medical Management	
12.	<b>12</b>	Internal Contamination: Medical Management	
13.	<b>14</b>	On-site activities: Managing the scene	
14.	<b>15</b>	On-site activities: Triage	
15.	<b>16</b>	Dosimetry	
16.	<b>18</b>	Acute Radiation Syndrome (ARS) and Cutaneous Radiation Injuries (CRI)	
17.	<b>19</b>	Combined Trauma Management	
18.	<b>20</b>	Group Work - Table top exercise on RDD/ Dirty Bomb	
19.	<b>22</b>	New technological advancements in the medical management of Radiation Emergencies	
20.	<b>23</b>	Psychosocial Support in Management of Radiation and Nuclear Emergencies	
21.	<b>24</b>	Risk communication	
22.		Pre Training Test	
23.		Post Training Test	
24.		Training Feedback Questionnaire	

**Day wise Training Schedule for Medical management of radiological and nuclear emergencies**  
**(4 Days)**

<b>Time</b>	<b>Session No.</b>	<b>Topic</b>
<b>DAY 1</b>		
8:30 – 9:00 AM		Registration
9:00- 9:30 AM		High Tea
9:30 – 10:00 AM		Inaugural Function
10:00 - 10:30 AM		Pre Test
10:30-11:00 AM	<b>1</b>	Introduction to Radiation
11:00 -11:30 AM	<b>2</b>	Fundamentals of Radioactivity
11:30-12:30 PM	<b>3</b>	Biological Effects of Ionizing Radiation
12:30-1:15 PM	<b>4</b>	Overview of Radio-Nuclear Emergencies: Radiation Accidents in Nuclear Power Plants - Experiences from the Past
1:15 - 2:00 PM		Lunch
2:00 - 2:45 PM	<b>5</b>	Disaster Management: An overview (Radio-nuclear emergencies)
2:45 - 3:15 PM	<b>6</b>	Radiation Therapy and Industrial Radiography
3:15 - 4:00 PM	<b>7</b>	Group demonstration on: o Radiation Monitoring System (RMS) / instruments o Inverse Square Law, shielding for Alpha, Beta & Gamma radiation
4:00 - 4:15 PM		Tea Break
4:15 - 5:00 PM	<b>8</b>	Orphan sources and RDD/ dirty bomb
05:00-05:30 PM	<b>9</b>	Long Term Effects of Radiation
<b>DAY 2</b>		
9:00 - 9:15 AM		Recap of day 1
09:15-12:15 PM	<b>10</b>	Group visit - Environmental Survey Laboratory (ESL) and demonstration of Whole-body counter: Role and functions and Exposure assessment
12:15 - 1:00 PM		Lunch
1:00-1:30 PM	<b>11</b>	External Contamination: Medical Management
01:30-02:00 PM	<b>12</b>	Internal Contamination: Medical Management
02:00-03:00 PM	<b>13</b>	Visit to Personnel Decontamination Center and Demonstration of decontamination procedure
03:00-03:30 PM	<b>14</b>	On-site activities: Managing the scene
3:30 - 3:45 PM		Tea break
03:45-04:45 PM	<b>15</b>	On-site activities: Triage
04:45-5:15 PM	<b>16</b>	Dosimetry

<b>DAY 3</b>		
09:00-12:00 PM	<b>17</b>	Visit to Atomic Power Plant
12:00 - 1:30 PM		Lunch
1:30 - 1:45 PM		Recap of day 2
1:45 - 3:00 PM [ 1:45 – 2:00 PM – ARS; 2:00 – 3:00 PM – CRI]	<b>18</b>	Acute Radiation Syndrome (ARS) + Cutaneous Radiation Injuries (CRI)
3:00 -3:30 PM	<b>19</b>	Combined Trauma Management
3:30 – 3:45 PM		Tea break
3:45 - 4:45 PM	<b>20</b>	Group Work - Table top exercise on RDD/ Dirty Bomb – highlighting involve multiple disciplines, such as emergency response, radiation safety, and medical management
4:45 - 6:00 PM	<b>21</b>	Group presentation - Table top exercise on RDD/ Dirty Bomb
<b>DAY 4</b>		
9:00 - 9:15 AM		Recap of day 3
09:15-09:45 AM	<b>22</b>	New technological advancements in the medical management of Radiation Emergencies
9:45 - 10:00 AM		Tea break
10:00-12:00 PM	<b>23</b>	Psycho-social care (Basic technique) followed by group exercise
12:00 - 12:30 PM	<b>24</b>	Risk communication <ul style="list-style-type: none"> <li>• Fundamental principles of communication</li> <li>• Communication methods – Incl. Media</li> <li>• Public information management</li> <li>• Communication to medical professionals</li> </ul> To be followed by group exercise
12:30 - 1:30 PM		Lunch
1:30 - 2:00 PM		Post Test
2:00 - 2:30 PM		Feedback
2:30 - 4:00 PM		Valedictory

### List of Abbreviations

<b>Abbreviation</b>	<b>Full Form</b>
AERB	Atomic Energy Regulatory Board
ALARA	As Low As Reasonably Achievable
ARS	Acute Radiation Syndrome
BARC	Bhabha Atomic Research Centre
BMT	Bone Marrow Transplant
CDC	Centers for Disease Control and Prevention
Gol	Government of India
HEOC	Health Emergency Operations Centre
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IR	Industrial Radiography
IUPAC	International Union of Pure and Applied Chemistry
LINAC	Linear Accelerator
MoHFW	Ministry of Health and Family Welfare
NCRP	National Council on Radiation Protection and Measurements (USA)
NDRF	National Disaster Response Force
NPP	Nuclear Power Plant
NPCIL	Nuclear Power Corporation of India Ltd.
OSHA	Occupational Safety and Health Administration
PPE	Personal Protective Equipment
RDD	Radiological Dispersal Device
RED	Radiological Exposure Device
REMM	Radiation Emergency Medical Management
RSO	Radiological Safety Officer
TBSA	Total Body Surface Area
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization

# Chapter 1

## Introduction to Radiation

### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand what is radiation, its sources and types.
- Understand the application of radiations

### 1. Introduction

Radiation is the process by which energy is emitted and transmitted through space or a material medium, either in the form of waves (such as electromagnetic radiation) or particles (such as alpha and beta particles).

#### ❖ Standard Definitions:

- **Radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium (ICRP, 2007)**
  - **Radioactivity is the property possessed by some elements (or isotopes) of spontaneously emitting ionizing radiation as a result of the disintegration of their atomic nuclei. (IAEA, 2004)**
  - **Isotopes are nuclides with the same number of protons (same atomic number) but different numbers of neutrons (and hence different mass numbers). (IAEA, 2004)**
  - **A radioisotope (or radionuclide) is a radioactive isotope, i.e., it spontaneously disintegrates, emitting ionizing radiation. (ICRP, 2007)**
- ❖ Radiation occurs naturally; it was not invented but discovered. People are constantly exposed to radiation. For example, radon in the air, potassium in food and water, and uranium,

thorium, and radium in the earth's crust are all sources of radiation. With advancements in science and technology, humans have also developed artificial (man-made) sources of radiation, such as medical diagnostic tools, nuclear reactors, and radiation-based industrial processes.

- ❖ Radiation offers significant benefits across diverse fields—such as medicine, industry, and energy production. However, improper management of ionizing radiation can harm biological tissues, potentially causing mutations, cancer, or radiation sickness at high exposure levels. Therefore, a thorough understanding of its types, sources, applications, and health implications is essential to ensure radiation is used safely and effectively.

## **2. History of Radiation**

- ❖ The history of radiation is closely linked to the discovery of atomic structure and the development of modern physics. The story began in 1895 when Wilhelm Conrad Roentgen, a German physicist, discovered X-rays while experimenting with cathode rays. This unexpected discovery earned him the first Nobel Prize in Physics in 1901 and marked the beginning of radiologic science.
- ❖ In 1896, French physicist Henri Becquerel discovered natural radioactivity while studying phosphorescent materials. He observed that uranium salts emitted radiation that could fog photographic plates, even in the absence of sunlight. His work was further developed by Marie and Pierre Curie, who in 1898 isolated two new radioactive elements: polonium and radium. Marie Curie became the first person to win two Nobel Prizes—in Physics and Chemistry—for her pioneering work.
- ❖ By the early 20th century, scientists like Ernest Rutherford advanced the understanding of radiation by identifying alpha, beta, and gamma radiation and proposing the nuclear model of the atom. His experiments laid the foundation for nuclear physics.
- ❖ During World War II, knowledge of nuclear fission led to the development of nuclear weapons under the Manhattan Project, and later to nuclear power.
- ❖ Over time, the medical field embraced radiation for diagnostic imaging (e.g., X-rays, CT scans) and cancer treatment. However, harmful effects from overexposure, including radiation sickness

and cancer, led to the development of radiation protection standards and radiation monitoring tools like dosimeters.

<b>Year</b>	<b>Scientist(s)/ Organization</b>	<b>Discovery/Event</b>	<b>Significance</b>
1800	William Herschel	Discovered infrared radiation	First evidence of radiation beyond visible light
1801	Johann Wilhelm Ritter	Discovered ultraviolet radiation	Extended the known spectrum on the high-energy end
1864	James Clerk Maxwell	Developed electromagnetic theory	Theoretical basis for all electromagnetic radiation
1887	Heinrich Hertz	Demonstrated existence of radio waves	Experimentally confirmed Maxwell's theory
1895	Wilhelm Roentgen	Discovered X-rays	First ionizing radiation used for medical imaging
1896	Henri Becquerel	Discovered natural radioactivity in uranium salts	Found that radiation could occur spontaneously from elements
1898	Marie and Pierre Curie	Isolated radium and polonium; coined the term radioactivity	Pioneered the study of radioactive elements
1900	Paul Villard	Identified gamma rays	Discovered high-energy electromagnetic radiation emitted from nuclei
1903	Ernest Rutherford & Soddy	Explained radioactive decay and transmutation of elements	Established the concept of nuclear decay chains
1911	Ernest Rutherford	Proposed the nuclear model of the atom	Demonstrated that atoms have a dense, positively charged nucleus
1912	Victor Hess	Discovered cosmic rays during balloon experiments	Proved that ionizing radiation comes from space

1932	James Chadwick	Discovered the neutron	Completed the basic model of the atomic nucleus
1934	Irène & Frédéric Joliot-Curie	Discovered artificial radioactivity	Enabled production of radioactive isotopes for medicine and research.
1938–1939	Lise Meitner, Otto Hahn, Fritz Strassmann	Discovered and explained nuclear fission	Led to advancement of nuclear reactors and weapons programs.
1942	Enrico Fermi & team	Built first nuclear reactor (Chicago Pile-1)	Initiated controlled nuclear chain reactions
1945	Manhattan Project scientists	Developed and used the first nuclear weapons	Demonstrated the large-scale destructive power of radiation
1946	United Nations (UN)	Establishment of United Nations Atomic Energy Commission (UNAEC)	First global attempt to control nuclear activities.
1953	United States (Eisenhower's Atoms for Peace)	UN speech advocating peaceful nuclear use	Paved way for IAEA formation.
1954	Union of Soviet Socialist Republics (USSR)	Obninsk – first nuclear power plant connected to grid	Began the era of peaceful nuclear energy generation.
1957	International Atomic Energy Agency (IAEA)	IAEA founded	Promotes safe, secure, peaceful nuclear technology; sets global radiation safety and emergency standards.
1957	United Kingdom (Sellafield)	Windscale fire	First major nuclear reactor accident; increased global safety scrutiny.
1957	Union of Soviet Socialist Republics (USSR)	Kyshtym disaster (Mayak)	One of the world's worst nuclear waste accidents; highlighted dangers of poorly controlled nuclear waste.
1963	Global	Partial Nuclear Test Ban Treaty	Reduced global radioactive fallout by banning atmospheric nuclear tests.

1970	United Nations & International Atomic Energy Agency	Non-Proliferation Treaty (NPT) in force	Strengthened IAEA's inspection and safeguards role.
1979	United States of America	Three Mile Island accident	Partial core meltdown; triggered major safety and operational reforms.
1986	Union of Soviet Socialist Republics (USSR) /Ukraine	Chernobyl disaster	Worst nuclear accident in history; led to IAEA's post-accident safety conventions and global emergency response reforms.
1999	Japan	Tokaimura criticality accident	Highlighted risks in fuel-processing facilities; strengthened regulatory controls.
1996	United Nations	Comprehensive Test Ban Treaty (CTBT)	Aimed to stop all nuclear explosive testing; established global radiation monitoring network.
2011	Japan	Fukushima Daiichi nuclear disaster	Resulted from earthquake/tsunami; led to the IAEA Action Plan on Nuclear Safety and modernized safety protocols worldwide.
2016– present	International Atomic Energy Agency (IAEA) & global agencies	Expansion of radiation protection standards & emergency preparedness	Increasing focus on harmonizing radiation protection, medical use of radiation, and nuclear emergency response.
2022– present	International Atomic Energy Agency (IAEA) & Ukraine	Nuclear safety crisis at Zaporizhzhia (occupied nuclear plant)	First time a major nuclear power plant became part of an active warzone; IAEA established continuous on-site monitoring missions.

Table no.1.1- History of Radiation

### 3. Types of radiation

Radiation is categorized into two types: **ionizing** and **non-ionizing**.

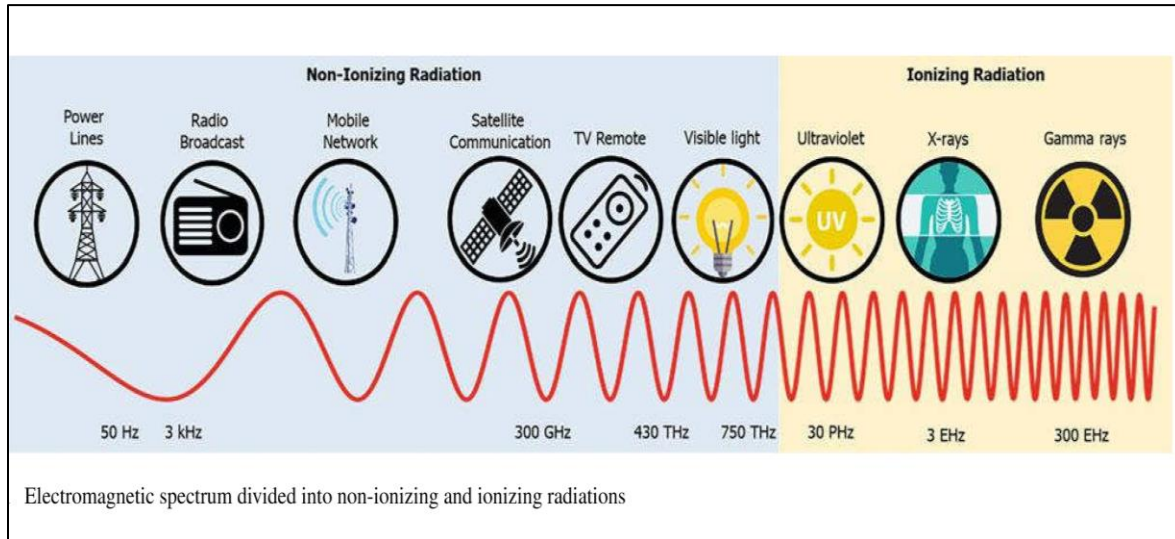


Fig.no. 1.1 - Electromagnetic Spectrum: Types of Radiation

#### 3.1 Ionizing radiation

❖ Ionizing radiation is radiation that carries enough energy to remove tightly bound electrons from the orbit of an atom, causing the atom to become charged or ionized. Ionizing radiation is classified into the following main types:

- Alpha particles ( $\alpha$ ): Large, positively charged particles with low penetration power. Stopped by a sheet of paper or skin but highly damaging if ingested or inhaled.
- Beta particles ( $\beta$ ): Electrons or positrons with greater penetration than alpha particles, capable of causing skin burns.
- Gamma rays ( $\gamma$ ) and X-rays: High-energy photons with significant tissue penetration; require dense shielding like lead.
- Neutrons: Uncharged particles with indirect ionizing ability, typically encountered in nuclear reactors.

- ❖ Ionizing radiation is capable of changing the chemical state of matter and subsequently causing biological damage and thus is potentially harmful to human health.

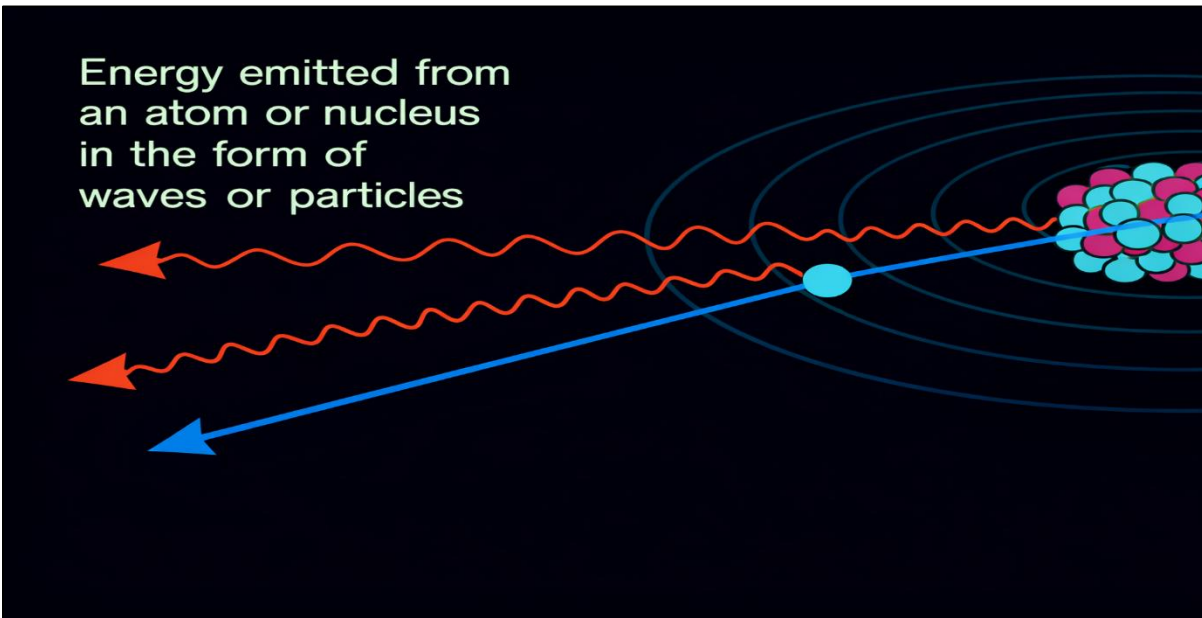


Fig.no. 1.2- Ionizing radiation

**Note:** This chapter will cover only ionizing radiation in detail.

### 3.1.1 Forms of Ionizing Radiation

- ❖ Particulate radiation: This type of radiation consists of atomic or subatomic particles—such as electrons, protons, neutrons, or alpha particles—that carry energy in the form of kinetic energy (mass in motion).
- ❖ Electromagnetic radiation: In this form, energy is transmitted through oscillating electric and magnetic fields that travel through space at the speed of light. Examples include X-rays and gamma rays.

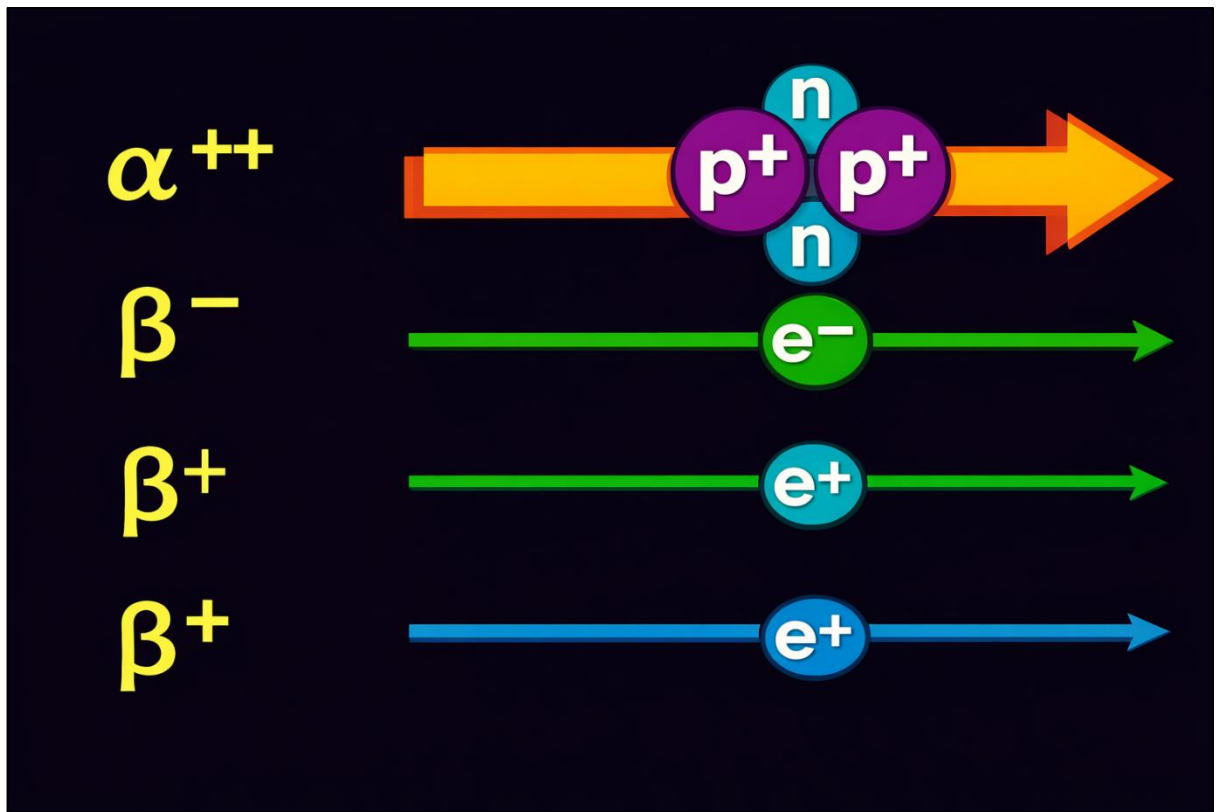


Fig.no. 1.3 —Alpha Particles and Beta Particles

- ❖ The figure 1.3 shows, directly ionizing radiation consisting of alpha particles and beta particles. They are considered directly ionizing because they carry a charge and can, therefore, interact directly with atomic electrons through coulombic forces (i.e. like charges repel each other; opposite charges attract each other).

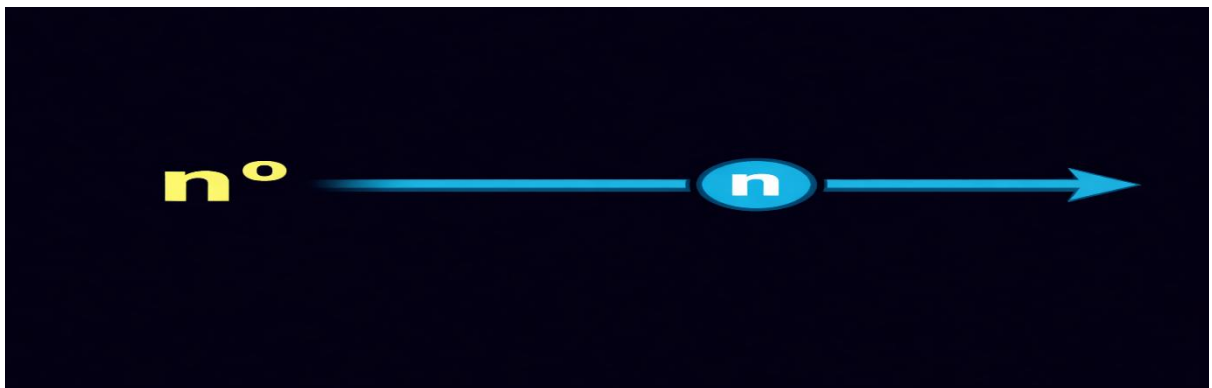


Fig.no. 1.4 —Neutrons

- ❖ The neutron (shown in the figure 1.4154) is an indirectly ionizing particle. It is indirectly ionizing because it does not carry an electrical charge. Ionization is caused by charged particles, which are produced during collisions with atomic nuclei.

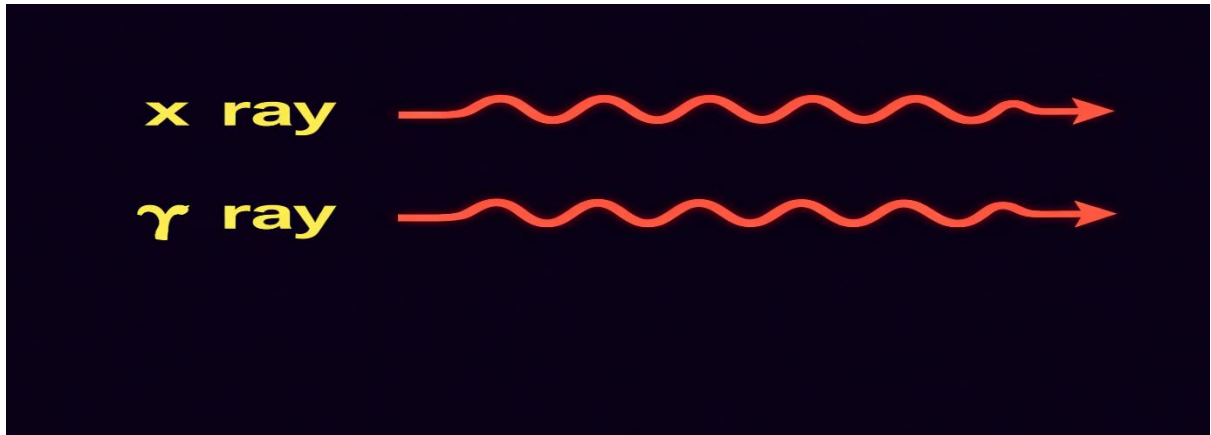


Fig.no. 1.5 —Gamma and X-rays

- ❖ The gamma and X rays (shown in the figure 1.5), are electromagnetic, indirectly ionizing radiation. These are indirectly ionizing because they are electrically neutral (as are all electromagnetic radiations) and do not interact with atomic electrons through coulombic forces.

**3.2 Nonionizing radiation** bounces off or passes through matter without displacing electrons. Examples include visible light and radio waves. Currently, it is unclear whether nonionizing radiation is harmful to human health.

**Note:** In the chapters that follows, the term **radiation** refers specifically to **ionizing radiation**.

#### 4. Sources of Radiation

Radiation originates from a variety of sources, broadly categorized into **natural** and **man-made (artificial)** origins. Understanding these sources is essential for managing exposure and applying radiation safely in science, medicine, industry etc.

#### 4.1 Natural Sources of Ionizing Radiation

Natural radiation is also known as Background radiation and has always existed in our environment. It includes:

- ❖ **Cosmic Radiation/Space Radiation:** The energetically charged particles from outer space continuously hit the earth's atmosphere. These particles and the secondary particles and photons they create are called space or cosmic radiation. Because the atmosphere provides some shielding against space radiation, the intensity of this radiation increases with altitude above sea level.
- ❖ **Terrestrial Radiation (Primordial radio nuclides):** Terrestrial radiation refers to radiation emitted from radioactive materials in the earth's rocks, soils, and minerals. Radon (Rn); radon progeny, the relatively short-lived decay products of radium ( $^{226}\text{Ra}$ ); potassium ( $^{40}\text{K}$ ); isotopes of thorium (Th); and isotopes of uranium (U) are the elements responsible for most terrestrial radiation. Radioactive Potassium ( $^{40}\text{K}$ ) is found in bananas, throughout the human body and in plant fertilizer.
- ❖ **Internal Radionuclides:** Radioactive material in the environment can enter the body through different routes of exposure, for example, the air people breathe and the food they eat; or through an open wound. Natural radionuclides that can enter the body include isotopes of uranium, thorium, radium, radon, polonium, bismuth, and lead in the  $^{238}\text{U}$  and  $^{232}\text{Th}$  decay series. In addition, the body contains isotopes of potassium ( $^{40}\text{K}$ ), and carbon ( $^{14}\text{C}$ ).
- ❖ **Radon Gas** (a radioactive gas found dispersed in the air): Radon gas is a naturally occurring, radioactive noble gas that is colorless, odorless, and tasteless. It is produced from the decay of uranium found in soil, rock, and groundwater, and can seep into buildings through cracks in foundations, floors, and walls. Radon tends to accumulate in enclosed spaces, particularly basements and ground floors, making indoor environments a primary source of exposure. When inhaled, radon and its radioactive decay products emit alpha particles that can damage lung tissue, significantly increasing the risk of lung cancer over prolonged exposure. Since radon cannot be detected by human senses, testing is essential to identify elevated levels. If

high concentrations are found, mitigation methods such as improving ventilation, sealing entry points, or installing radon reduction systems can effectively reduce exposure.

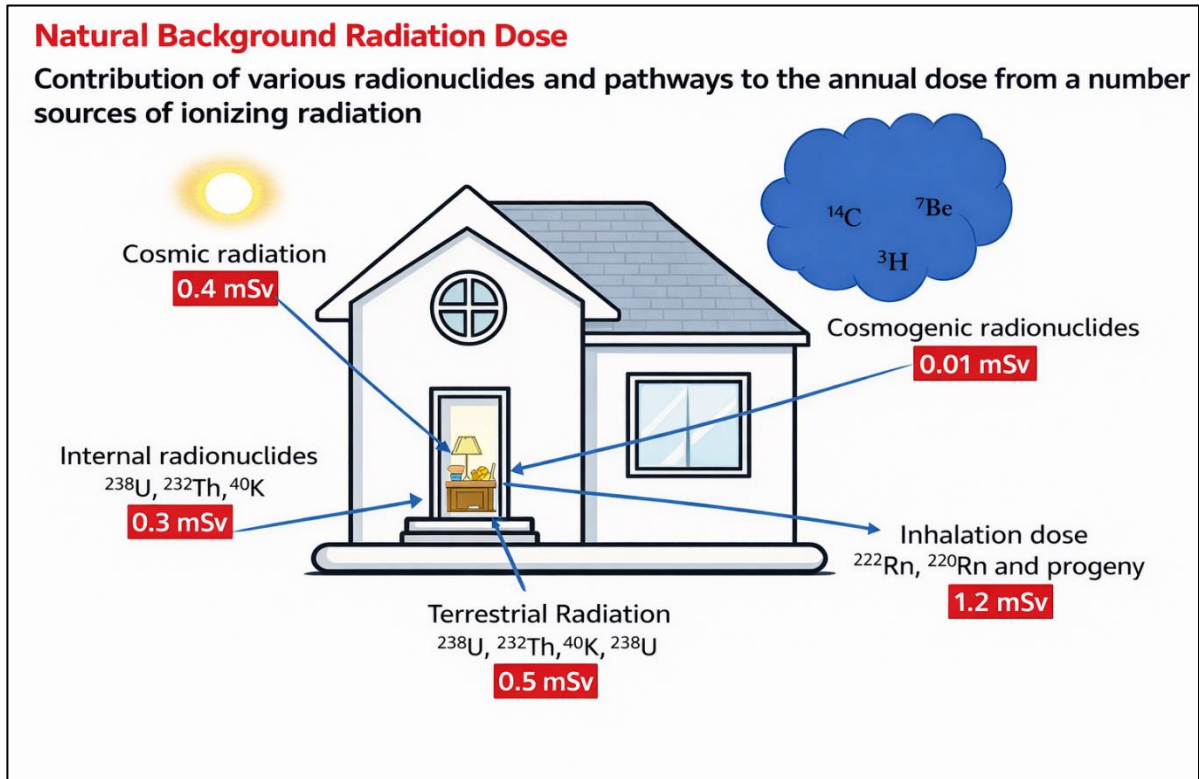


Fig. no. 1.6 -- Natural Sources of Radiation




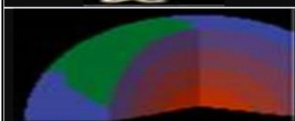
Source	Annual Dose ( $\mu\text{Sv}/\text{Year}$ )	Percent of Total Annual Dose
 Cosmic rays (Radiation from the sun and outer space)	400	16.7%
 Radon	1200	50%
 Human Body	300	12.5%
 The Earth	500	20.8%
<b>Ref. UNSCEAR 2000</b>	<b>Total</b>	<b>2400</b>

Fig.no. 1.7- Natural Background Radiation

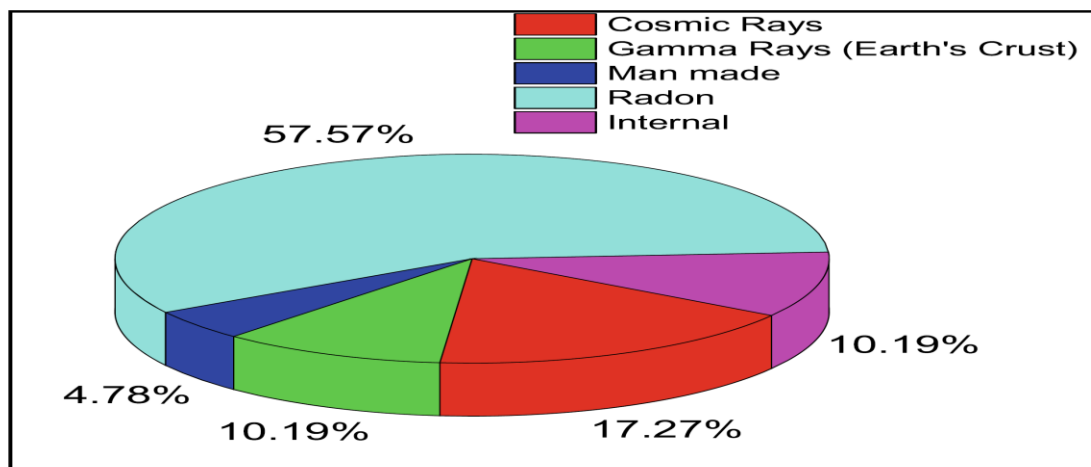


Fig.no. 1.8- Contribution of sources to environmental radiation

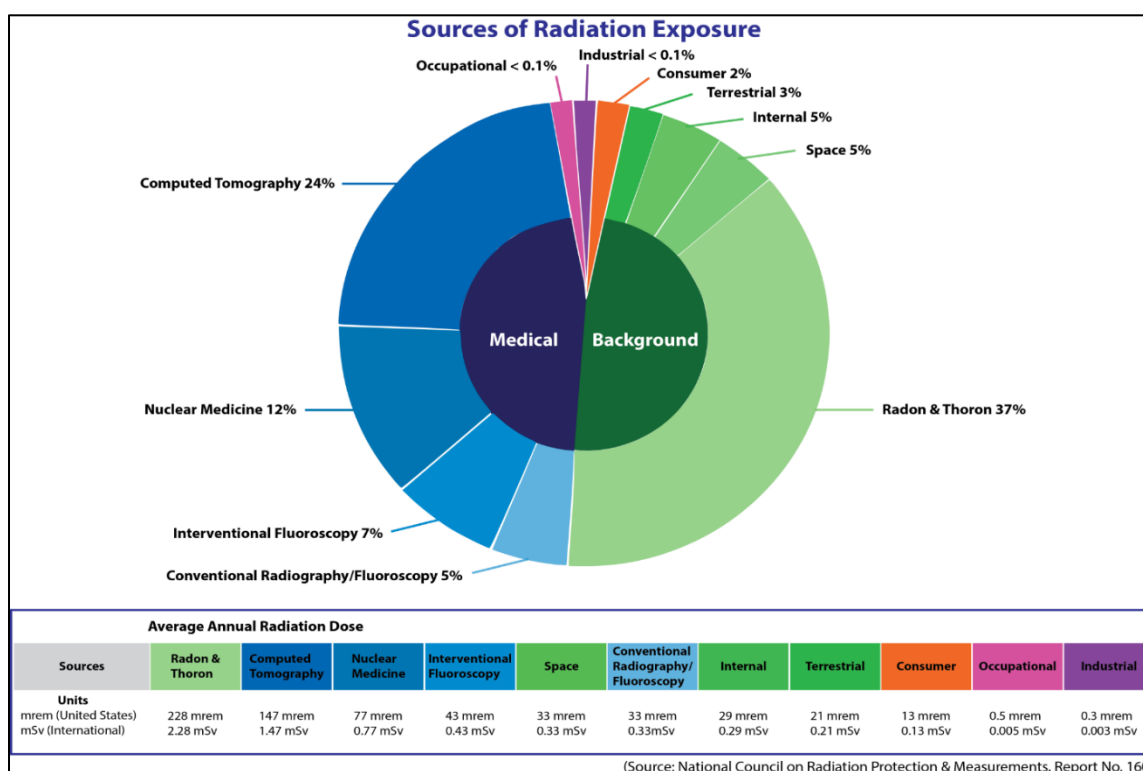


Fig.no. 1.9 —Sources of Radiation Exposure

## 4.2 Man-Made (Artificial) Sources of Radiation

Artificial sources of radiation arise from human activities in medicine, industry, energy production, research, and consumer use. Major categories include:

- ❖ **Medical Radiation (X-rays, Nuclear medicine, Radiotherapy):** Radiation is an important tool of diagnostic medicine and treatment, and, in this use, is the main source of exposure to human-made radiation. Exposure is deliberate and directly beneficial to the patients exposed. Generally, medical exposures result from beams directed to specific areas of the body. Thus, all body organs generally are not irradiated uniformly. Radiation and radioactive materials are also used in a wide variety of pharmaceuticals and in the preparation of medical instruments, including the sterilization of heat-sensitive products such as plastic heart valves. Nuclear medicine examinations and treatment involve the internal administration of radioactive compounds, or radiopharmaceuticals, by injection, inhalation, consumption, or insertion. Even then, radionuclides are not distributed uniformly throughout the body.
- ❖ **Industrial Sources (Industrial radiography, Smoke detectors):** Industry uses radiation for several applications, including industrial radiography, quality control, and process monitoring. Additional exposure sources include emissions or effluents from uranium mines, fuel fabrication facilities, nuclear reactors, mineral extraction operations, and transportation of radioactive materials. Many household and commercial smoke detectors use a small, sealed radioactive source—typically Americium-241 (Am-241). The isotope emits alpha particles that ionize air in the detection chamber. When smoke enters, ionization is disrupted and the alarm is triggered. The quantity of radioactive material is extremely small, securely encapsulated, and poses negligible exposure risk during normal use. However, proper disposal is advised to prevent environmental contamination. Workers may also be exposed occupationally to radiation in medicine, aviation, research, education, and regulatory or government agencies, depending on their job responsibilities.

- ❖ **Nuclear Power and Weapons (IND, dirty bomb):** Radiation is released during nuclear fission in power reactors. Although routine releases are strictly controlled, accidents—such as Chernobyl and Fukushima—can result in significant environmental contamination. Nuclear weapons, including Improvised Nuclear Devices (INDs) and radiological dispersal devices (dirty bombs), can also release large amounts of radiation.
- ❖ **Radioactive Waste:** Radioactive waste arises from nuclear power generation, medical and industrial applications, and research activities. This waste must be safely handled, treated, stored, and disposed of following stringent regulatory requirements to prevent contamination of people or the environment.
- ❖ **Consumer Products:** Some consumer products are sources of radiation. In some consumer products, such as smoke detectors, watches, or clocks, radiation is essential to the performance of the device. In other products or activities, such as smoking tobacco products or building materials, the radiation occurs incidentally to the product function. Commercial air travel is another consumer activity that results in exposure to radiation (from space/cosmic radiation).

## 5. Applications of Radiation

Radiation has become an indispensable tool across medicine, industry, agriculture, energy production, and scientific research. When used responsibly and in compliance with safety standards, it offers significant benefits with minimal risk.

### ❖ **Medical Applications:**

In medicine, radiation is used extensively for both diagnosis and treatment. Diagnostic applications—such as X-rays, CT scans, conventional radiography, and nuclear medicine procedures like PET scans—typically involve low doses delivered over very short periods and are crucial for detecting and evaluating disease. Therapeutic applications, by contrast, use high-energy ionizing radiation (e.g., gamma rays, electron beams, and X-rays) to destroy cancer cells by damaging their DNA and preventing replication, forming the basis of modern radiation therapy.

Brachytherapy delivers radiation internally through implanted radioactive sources, including removable seeds with long half-lives and permanent seeds with shorter half-lives. These medical technologies have transformed healthcare by enabling more accurate diagnosis and effective cancer treatment.

❖ **Industrial Applications:**

Radiation is used in non-destructive testing (NDT) to inspect materials and welds for internal defects without damaging them. It's also used in quality control, thickness gauging, and level measurements in manufacturing processes. In food irradiation, gamma rays are used to kill bacteria and parasites, extending shelf life and improving food safety.

❖ **Energy Production:**

Nuclear power plants harness energy from controlled nuclear fission reactions. This form of energy is low in greenhouse gas emissions and contributes to the global electricity supply.

❖ **Scientific and Space Research:**

Radiation is used in radiotracer studies, environmental monitoring, and in space exploration (e.g., power for spacecraft through radioisotope thermoelectric generators).

While the benefits are vast, safety precautions and regulation are essential to minimize health risks. Radiation must be used with strict adherence to safety standards and the ALARA principle (As Low as Reasonably Achievable).

❖ **Agriculture and Food Preservation:**

- Radiation plays a significant role in agriculture and food preservation by enabling the development of high-yield, disease-resistant crop varieties through mutation breeding. It is also applied in pest control through the **Sterile Insect Technique (SIT)**, which suppresses insect populations without the use of chemical pesticides.

- **Crop Improvement through Radiation:** BARC, India, has developed **71 radiation-bred crop varieties** as of 24 July 2025 using radiation-induced mutagenesis and cross-breeding. These include rice, wheat, pulses, oilseeds, jute, and sorghum, with desirable traits such as early maturity and tolerance to biotic and abiotic stress. All these varieties are approved for and under commercial cultivation.
- **Cold Chain Radiation Technologies:** Cold chain innovations developed by BARC integrate radiation-based principles—primarily cryogenic refrigeration using liquid nitrogen and radiation-enabled preservation—to maintain product quality during storage and transport.
  - **SHIVAY:** SHIVAY is a radiation-assisted cold chain transportation system that uses liquid nitrogen (LN<sub>2</sub>) as a refrigerant. Although LN<sub>2</sub> itself is not radioactive, the technology draws on BARC’s expertise in radiation physics, cryogenics, and material compatibility under low-temperature conditions. It provides stable, ultra-low temperatures without mechanical refrigeration, making it suitable for transporting perishables, biomedical products, and radiation-processed foods.
  - **MATSYA:** MATSYA is a cold-chain preservation system installed on the Sagar Harita fishing vessel. It is designed to maintain the freshness of fish catch by ensuring rapid onboard chilling and temperature stability, essential for seafood intended for radiation processing such as food irradiation for shelf-life extension, microbial reduction, and parasite control. The system complements radiation-based food preservation by ensuring that products remain in optimal condition before and after irradiation treatment, thereby safeguarding quality and nutritional value.
- **Food Irradiation for Shelf-Life Extension:** Food irradiation is an established technology used to reduce microbial load, inhibit sprouting, control insect infestation, and extend the shelf life of agricultural and food products. India has progressively expanded its radiation processing capacity through both government and private sector initiatives.

- **Regulatory and Technological Milestones**

- India granted its first regulatory approval for food irradiation in 1994, marking the formal recognition of radiation processing as a safe and effective food preservation method.
- The first Technology Demonstration Plant (TDP) for food irradiation became operational on 1 January 2000 at the Radiation Processing Plant (RPP), Vashi, Navi Mumbai, operated by the Board of Radiation and Isotope Technology (BRIT)—a government organization under the Department of Atomic Energy (DAE).
- A second TDP, KRUSHAK, was commissioned on 31 October 2002 at Lasalgaon, Nasik, Maharashtra, to demonstrate large-scale radiation processing for agricultural commodities such as onions, potatoes, and cereals.

- **Current Radiation Processing Capacity in India**: At present, 28 food irradiation facilities operate across the country. These include:

- Government-operated radiation processing units fall under the Department of Atomic Energy (DAE) and are primarily managed by Board of Radiation and Isotope Technology (BRIT), Bhabha Atomic Research Centre (BARC), Raja Ramanna Centre for Advanced Technology (RRCAT), Indore and other institutions of the Department of Atomic Energy (DAE). Government facilities generally focus on public-sector service, export-oriented treatment, training, and technology dissemination.
- Private sector facilities, which account for 22 of the 28 plants, supporting commercial-scale processing. Some examples include: Solas Industries, operational since 2021 at Mathura, Uttar Pradesh and Q-Line Health Care, with a new facility under construction at Lucknow, Uttar Pradesh.

- **Shelf-life enhancement results**: Radiation processing has demonstrated significant extension of shelf life for several commodities such as mangoes (up to 35 days for export by sea), onions (up to 7.5 months) and potatoes (up to 8 months).

- **Radura Logo and Consumer Transparency:** The Radura logo is used on food packaging to indicate that a product has been treated with ionizing radiation. As mandated by FSSAI:
  - The logo must appear alongside the phrases **“Treated with radiation”** or **“Treated by irradiation.”**
  - This labeling system ensures consumer transparency and supports informed decision-making.
  - It forms part of the broader **“Circle of Trust”** approach, which involves coordinated responsibility between the **government, industry, and consumers** to ensure safe, acceptable, and properly communicated food irradiation practices.
  - Irradiation enhances shelf-life, reduces spoilage, and ensures microbial safety without affecting nutritional quality.
- These radiation technologies contribute significantly to food security, export quality, and reduction of post-harvest losses.



Fig. no. 1.10- Radura logo

## Take Home Message:

- ❖ Radiation is everywhere; awareness is the key.
- ❖ Radiation is energy emitted as particles or waves, originating from natural and man-made sources.
- ❖ Radiation includes different types such as ionizing (X-rays, gamma rays, alpha/beta particles) and non-ionizing radiation.
- ❖ Radiation exposure may be due to natural or man-made sources.
- ❖ Natural sources include cosmic rays, terrestrial radionuclides, and radon; artificial sources include medical, industrial, and nuclear applications.
- ❖ Human beings are exposed to natural background radiation since very beginning
- ❖ There are multiple applications of radiation in our lives, including medical, research, industrial, agriculture, energy etc.

## References (Adapted from)

- IAEA (2023) "Introduction to Radiation." [<https://www.iaea.org/resources/rpop/resources/training-material>]
- IAEA (2023) "Applications of Radiation." [<https://www.iaea.org/resources/rpop/resources/training-material>]
- IAEA (<https://www.iaea.org/newscenter/news/what-is-radiation>)
- Health Physics Society. (2022). "Historical Timeline of Radiation."
- Health Physics Society. (2022). "Radiation Basics."
- Badash, L. (1965). Radioactivity in America: Growth and Decay of a Science. Johns Hopkins Press.
- Oxford University Press Pais, A. (1986). Inward Bound: Of Matter and Forces in the Physical World.
- Hall, E. J., & Giaccia, A. J. (2018). Radiobiology for the Radiologist. Wolters Kluwer.
- U.S. Nuclear Regulatory Commission (NRC). (2023). "Uses of Radiation."
- U.S. Nuclear Regulatory Commission (NRC). (2023). "History of Radiation Discovery."
- U.S. Nuclear Regulatory Commission (NRC). (2023). "What is Radiation?"
- WHO (2022) "Radiation: Health and Safety."
- WHO (2022) "Radiation in Medicine and Industry."

- Department of Energy:  
<https://www.energy.gov/sites/prod/files/2020/07/f77/2018%20Portsmouth%20ASER-introduction-to-radiation.pdf>
- ARC Radiological Physics and Advisory Division (RP&AD) Technical Reports
- FSSAI Guidance Notes: <https://fssai.gov.in/home/FSSAI-Guidance-Notes>
- Image:
  - Fig.no 1.7 [UNSCEAR 2000]
  - Fig.no 1.6, 1.8 [Handbook on Radiation Environment, Volume 1, Springer ([https://link.springer.com/chapter/10.1007/978-981-97-2795-7\\_2](https://link.springer.com/chapter/10.1007/978-981-97-2795-7_2))]
  - Fig.no. 1.9 [NCRP report no 160]
  - Fig.no. 1.10 (FSSAI)

### **Suggested Reading**

- Hall, E. J., & Giaccia, A. J. (2019). Radiobiology for the Radiologist (8th ed.). Wolters Kluwer.
- Booklet to Provide Basic Information Regarding Health Effects of Radiation (5th edition) (MoE, Govt. of Japan) [<https://www.env.go.jp/en/chemi/rhm/basic-info/1st/03-02-04.html>]
- IAEA (2010). Radiation Biology: A Handbook for Teachers and Students ([https://www-pub.iaea.org/MTCD/Publications/PDF/TCS-42\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/TCS-42_web.pdf))

## Chapter 2

### Fundamentals of Radioactivity

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand different types of radioactive decay (alpha, beta, and gamma), including their characteristics and nuclear transformations.
- Apply the concept of half-life to calculate remaining radioactive material over time and understand its practical implications in radiation protection and medical applications.
- Distinguish between radiation measurement quantities and units, such as exposure (R), absorbed dose (Gy), equivalent dose (Sv), and radioactivity (Bq), and relate them to biological risk.
- Understand basic radiation protection techniques and regulatory dose limits.

#### 1. Introduction

Radioactivity is a fundamental concept in nuclear science, medicine, and radiation safety. It refers to the spontaneous disintegration of unstable atomic nuclei, a process that results in the emission of radiation.

##### 1.1 Structure of the Atom

All matter in the universe, whether living or non-living, is composed of fundamental units called atoms.

**Atoms are the building blocks of matter, consisting of a central nucleus made up of protons (positively charged) and neutrons (uncharged), surrounded by electrons (negatively charged). The number of protons determines the atomic number and identity of the element.**

The structure of the atom has been developed through various scientific discoveries over time.

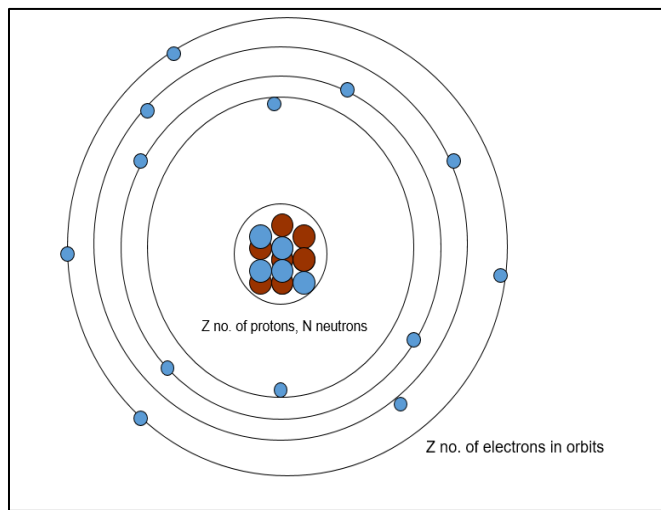


Fig.no. 2.1—Structure of an Atom

## 1.2 Nucleus:

- ❖ Protons and neutrons together form the nucleus of the atom.
- ❖ The nucleus determines the identity of the element and its atomic mass.
- ❖ Protons and neutrons have essentially the same mass but only the proton is charged while the neutron has no charge.

## 1.3 Elements

- ❖ An element is defined by the number of protons in the nucleus of its atoms, also known as the atomic number. This determines the chemical identity and properties of the element. In an electrically neutral atom, the number of electrons surrounding the nucleus is equal to the number of protons, ensuring overall charge balance.

## 1.4 Atomic Mass Unit (amu)

- ❖ The atomic mass of the proton and the neutron is approximately:
  - Proton =  $1.6726 \times 10^{-24}$  grams = 1.0073 amu
  - Neutron =  $1.6749 \times 10^{-24}$  grams = 1.0087 amu

❖ Thus, the neutron is just a little heavier than the proton.

## 1.5 Isotopes

Isotopes are variants of the same element that differ in neutron number. While most isotopes are stable, some are unstable and undergo radioactive decay to reach a more stable state.

**Isotopes are nuclides with the same number of protons (same atomic number) but different numbers of neutrons (and hence different mass numbers).** (IAEA, 2004)

## 2. Radioactivity and Radioactive Decay

**2.1 Radioactivity is the property possessed by some elements (or isotopes) of spontaneously emitting ionizing radiation as a result of the disintegration of their atomic nuclei.** (IAEA, 2004)

It was first discovered by Henri Becquerel in 1896 while studying the effects of uranium salts. Later, Marie and Pierre Curie expanded on this discovery by isolating other radioactive elements such as polonium and radium.

Radioactivity is measured using instruments like Geiger-Müller counters and expressed in units such as becquerels (Bq) or curies (Ci).

Radioactivity, while capable of causing health risks due to ionizing radiation, also offers significant benefits across multiple fields. In medicine, it is used for cancer treatment and advanced imaging techniques such as PET scans. In archaeology, carbon-14 dating helps determine the age of ancient artifacts. In the energy sector, radioactive fuels like uranium-235 play a crucial role in generating nuclear power.

## 2.2 Radioactive Decay

**Radioactive decay is the process by which an unstable atomic nucleus loses energy by emitting radiation, such as alpha, beta particles, or gamma rays.** (IAEA Safety Glossary, 2018)

At the atomic level, radioactivity occurs when there is an imbalance between the number of protons and neutrons in the nucleus, making it unstable. To reach a more stable configuration, the nucleus undergoes radioactive decay, transforming into a different element or isotope while emitting particles or electromagnetic waves.

Radioactive decay is the spontaneous transformation of an unstable atomic nucleus into a more stable one by emitting radiation. This radioactive event/process occurs in isotopes that have an imbalance between the number of protons and neutrons, resulting in nuclear instability and formation of new elements. To achieve stability, these nuclei release energy in the form of particles (such as alpha or beta particles) or electromagnetic waves (gamma rays). The nucleus undergoing this process is known as the parent isotope, while the resulting product is called the daughter isotope.

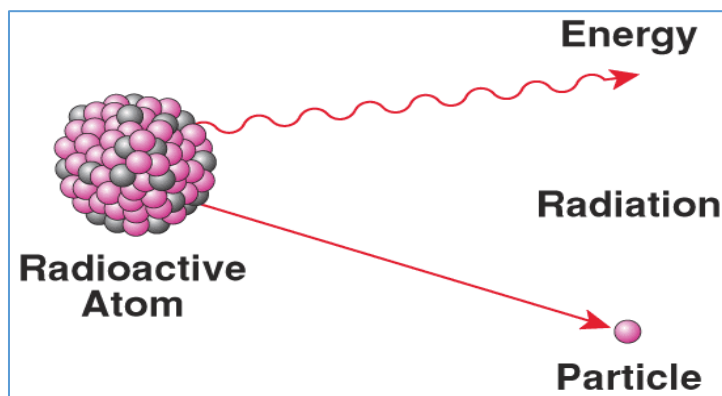


Fig.no. 2.2 – Radioactive Event

There are three primary types of radioactive emissions: alpha particles ( $\alpha$ ), beta particles ( $\beta$ ), and gamma rays ( $\gamma$ ). Alpha radiation consists of two protons and two neutrons and can be stopped by a sheet of paper. Beta radiation involves the emission of electrons or positrons and penetrates further than alpha but can be blocked by plastic or thin metal. Gamma radiation is a high-energy electromagnetic wave, extremely penetrating, and requires dense materials like lead for shielding.

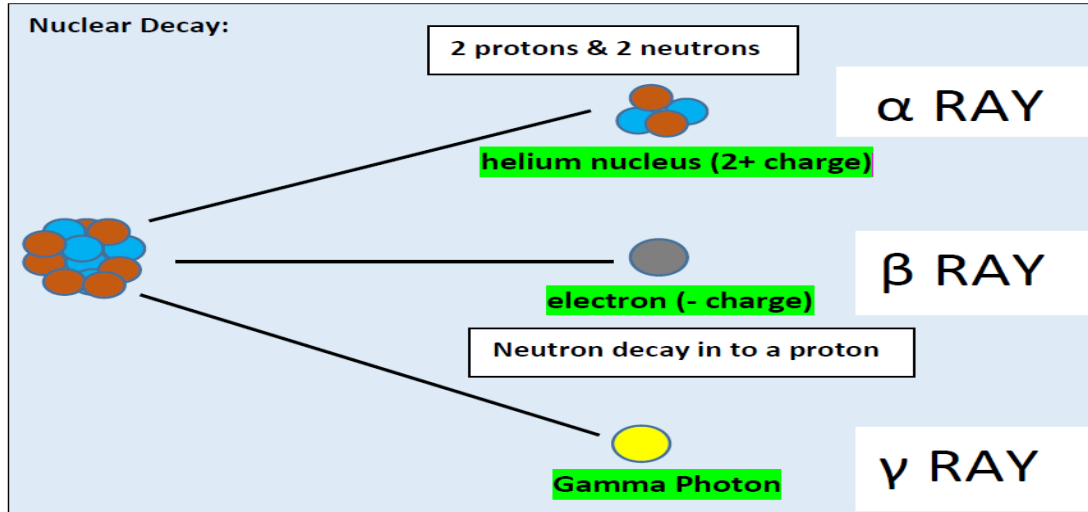


Fig. no. 2.3– Nuclear Decay

**2.2.1 Types of Radioactive Decay:** There are several types of radioactive decay such as:

- ❖ **Alpha Decay ( $\alpha$ ):** In alpha decay, the nucleus emits an alpha particle, which consists of two protons and two neutrons. This reduces the atomic number by two and the mass number by four. It occurs when the neutron-to-proton ratio is too low.
- ❖ **Beta Decay ( $\beta$ ):** In beta decay, a neutron is converted into a proton with the emission of an electron (beta-minus decay) or a proton is converted into a neutron with the emission of a positron (beta-plus decay). It occurs when there is a surplus of neutrons.

❖ **Gamma Emission ( $\gamma$ ):** Gamma decay often follows alpha or beta decay and involves the emission of high-energy gamma radiation without changing the number of protons or neutrons. Gamma rays are a form of electromagnetic radiation with significant penetration capabilities, and thus pose an external hazard. Usually accompanies alpha or beta decay. Does not change the atomic number or mass. Each radioactive isotope decays at a specific and predictable rate, expressed as its half-life—the time it takes for half of the radioactive atoms in a sample to decay. For example, carbon-14 has a half-life of 5,730 years, making it useful in radiocarbon dating for archaeological remains.

**Note: X-Ray Production:** Unlike alpha, beta, gamma rays which are produced by nuclear decay, the X-rays are produced when high-speed electrons are rapidly decelerated, typically by colliding with a metal target. However, X-rays like alpha, beta, gamma rays are forms of ionizing radiation.

Decay Mode	Characteristics of Parent Radionuclide	Change in Atomic Number (Z)	Change in Atomic Mass
Alpha	Neutron Poor	-2	-4
Beta	Neutron Rich	+1	0
Gamma	Excited state of nucleus	None	None
X-ray	Excited state in atomic orbits	None	None

Table no. 2.1- Summary of Radioactive Decay Mechanisms

### 3. Penetrating Power of Radiation

❖ Penetrating power refers to the ability of ionizing radiation to pass through matter. Different types of radiation have different abilities to penetrate materials, which is crucial in determining appropriate shielding and protection measures.

Type of Radiation	Symbol	Stopped by	Penetrating Power
Alpha ( $\alpha$ )	${}^4_2\alpha^{++}$	Paper, skin	Very low
Beta ( $\beta$ )	${}^0_{-1}\beta^{-}$	Plastic, glass	Moderate
Gamma & X-rays ( $\gamma$ )	${}^0_0\gamma$	Lead	High
Neutrons (n)	${}^1_0n$	Concrete, water	Very high

Table no. 2.2- Penetrating Power of Radiation

- Alpha particles are easily stopped and mainly pose internal hazards if ingested or inhaled.
  - Beta particles can penetrate skin and require moderate shielding.
  - Gamma rays and X-rays are highly penetrating and need dense shielding materials.
  - Neutrons, being uncharged, are highly penetrating and are best blocked by hydrogen-rich materials.
- ❖ The figure 2.4 demonstrates the penetrating distances of different types of ionizing radiation through various materials.

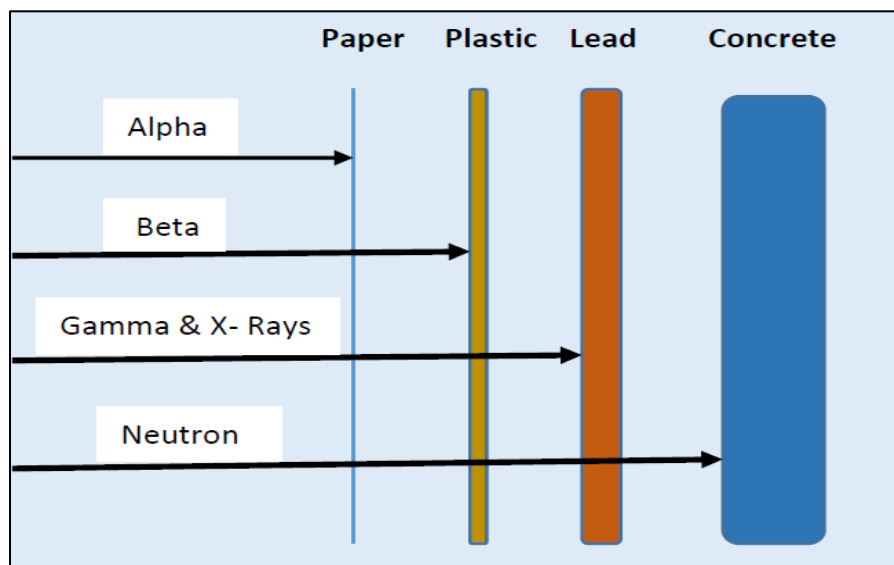


Fig.no. 2.4– Penetrating Power of radiation

#### 4. Half-Life of Radioactivity

- ❖ The half-life of radioactivity is the time required for half the nuclei in a sample of a radioactive substance to undergo radioactive decay. It is a fundamental property of each radioisotope and indicates the rate at which it loses its radioactivity. During each half-life, the quantity of radioactive material is reduced by 50%, but this process continues in an exponential pattern rather than reaching zero. For example, if a sample starts with 100 grams of a radioactive isotope with a half-life of 10 years, only 50 grams will remain after 10 years, 25 grams after 20 years, and so on.
- ❖ Half-life is crucial in understanding the stability and longevity of radioactive elements. Different isotopes have vastly different half-lives—ranging from fractions of a second to millions of years. For instance, Uranium-238 has a half-life of about 4.5 billion years, making it useful in geological dating, while Technetium-99m, used in medical imaging, has a half-life of only 6 hours, minimizing radiation exposure to patients.
- ❖ The half-life concept has widespread applications. In nuclear medicine, it helps determine how long a radiopharmaceutical remains active in the body. In archaeology, carbon-14 dating estimates the age of once-living materials by measuring the remaining carbon-14. In nuclear power and waste management, understanding half-life helps predict how long radioactive waste remains hazardous and requires containment.
- ❖ Importantly, the half-life is not affected by external factors such as temperature, pressure, or chemical bonding. It is purely a nuclear property that helps scientists model radioactive decay mathematically using exponential decay equations.
- ❖ The figure 2.5 illustrates the Radioactive Decay Curve, showing how the fraction of a radioactive substance decreases over time with each half-life.

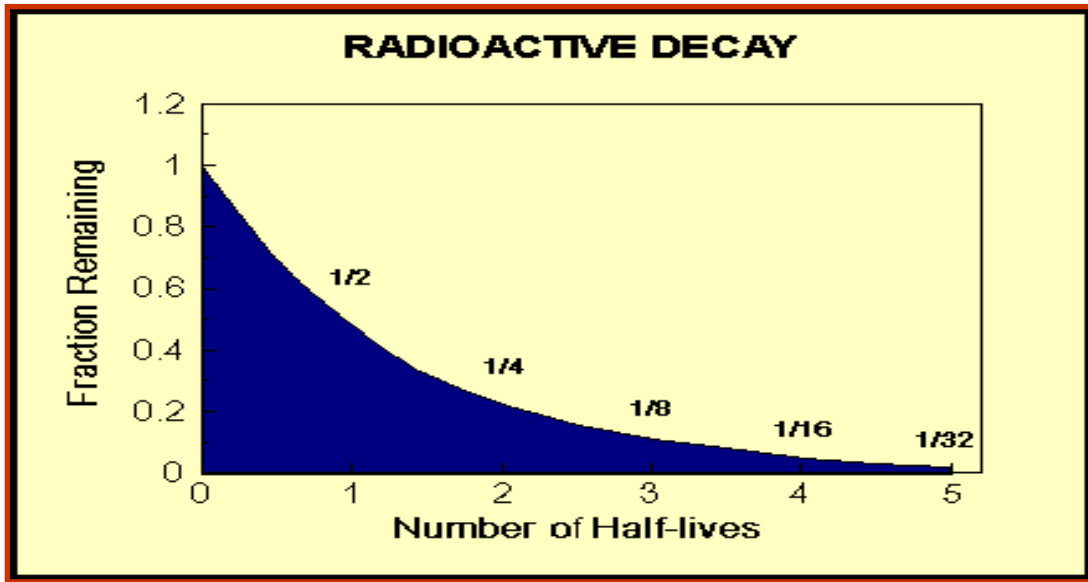


Fig.no. 2.5 – Radioactive Decay

## 5. Radiation Dosage and Measurement Units

### 5.1 Exposure

- ❖ Radiation exposure is a measure of the intensity of the radiation field. For X and gamma rays, exposure is precisely defined in terms of the amount of ionization produced in air by the radiation source. It is measured in units of coulombs per kilogram (C/kg) of air at NTP, and is directly related to the radiation fluence.
- ❖ The old unit for exposure is the roentgen (R). The roentgen (R) was originally defined as the amount of X radiation that produced 1 electrostatic unit (esu) of charge as a result of interactions in 1cc of dry air at NTP.  $1R=2.58 \times 10^{-4} C/kg$
- ❖ Some radiation passes through a volume of medium without interacting and, therefore, does no damage. Thus, only the radiation that interacts with the medium is measured. The SI unit for exposure is the coulomb per kilogram, or unit of charge generated per unit mass.

### 5.2 Radiation dosage

- ❖ Radiation dosage refers to the amount of radiation energy absorbed by matter, particularly biological tissue. Measuring radiation accurately is essential for ensuring safety in

environments like hospitals, nuclear power plants, and research labs. Radiation doses are quantified using several key units that describe different aspects of exposure and effect.

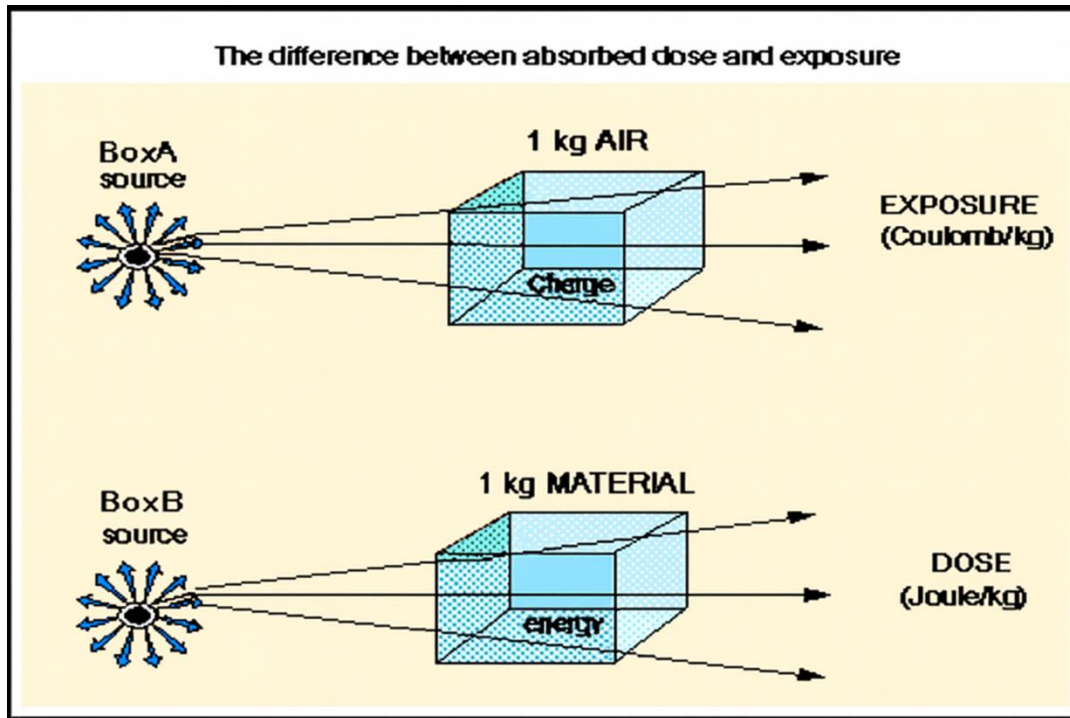


Fig. no. 2.6 - Dose and Exposure

❖ The figure 2.6 illustrates:

- **Box A – Exposure (Coulomb/kg)**

**Medium:** 1 kg of air.

**What's measured:** The electric charge produced in air by ionizing radiation (gamma or X-rays).

**Unit:** Coulomb/kg (SI) or Roentgen (R) (older unit).

**Key idea:** Exposure is about how much ionization happens in the air, not in human tissue. It's a measure of radiation's ability to ionize air molecules.

**Used for:** Primarily calibration of X-ray and gamma-ray sources.

- **Box B – Absorbed Dose (Gray)**

**Medium:** 1 kg of material (can be tissue, bone, water, etc.).

**What's measured:** The energy deposited in that material by radiation.

**Unit:** Joule/kg = Gray (Gy) in SI (older unit: rad).

**Key idea:** Absorbed dose measures the actual physical energy transferred to the material — important for assessing biological effects.

### 5.3 Key Units of Radiation Dose:

- ❖ Units of radiation can be broadly divided into units for the sources of radiation and units for the receiving side. Becquerel, a unit of radioactivity, is used for the sources of radiation. Units for the receiving side are Gray and Sievert. The Sievert accounts for both the type of radiation and its biological effects on tissues. It helps assess the potential health risk.
- ❖ When radiation passes through something, its energy is absorbed there. Gray is a unit for indicating the absorbed dose.

Type	What It Measures	Unit	Definition / Formula	Use
<b>Exposure</b>	Ionization in air (for gamma and X-rays only)	Roentgen (R)	1 R = depositing in dry air enough energy to cause $2.58 \times 10^{-4}$ coulombs per kg	Measures ability of photons to ionize air; not used for alpha, beta, or neutrons
<b>Radioactivity</b>	Rate of radioactive decay	Becquerel (Bq) Curie (Ci)	1 Bq = 1 decay/sec 1 Ci = $3.7 \times 10^{10}$ decays/sec	Describes the <i>source</i> activity, not the effect on tissue
<b>Absorbed Dose (D)</b>	Energy deposited per unit mass	Gray (Gy)	1 Gy = 1 joule/kg $D = \text{energy} / \text{mass}$	Indicates physical energy absorbed, same for all radiation types
<b>Equivalent Dose (H)</b>	Absorbed dose adjusted for type of radiation	Sievert (Sv)	$H = D \times WR$ (D in Gy, WR = radiation weighting factor)	Accounts for biological effectiveness of radiation type
<b>Effective Dose (E)</b>	Equivalent dose adjusted for tissue sensitivity	Sievert (Sv)	$E = \sum (H_T \times WT)$ ( $H_T$ = equivalent dose received by organ or tissue T, WT = tissue weighting factor for organ or tissue T)	Reflects overall risk to the whole body

Table no.2.3 --Summary of Radiation Measurement Units

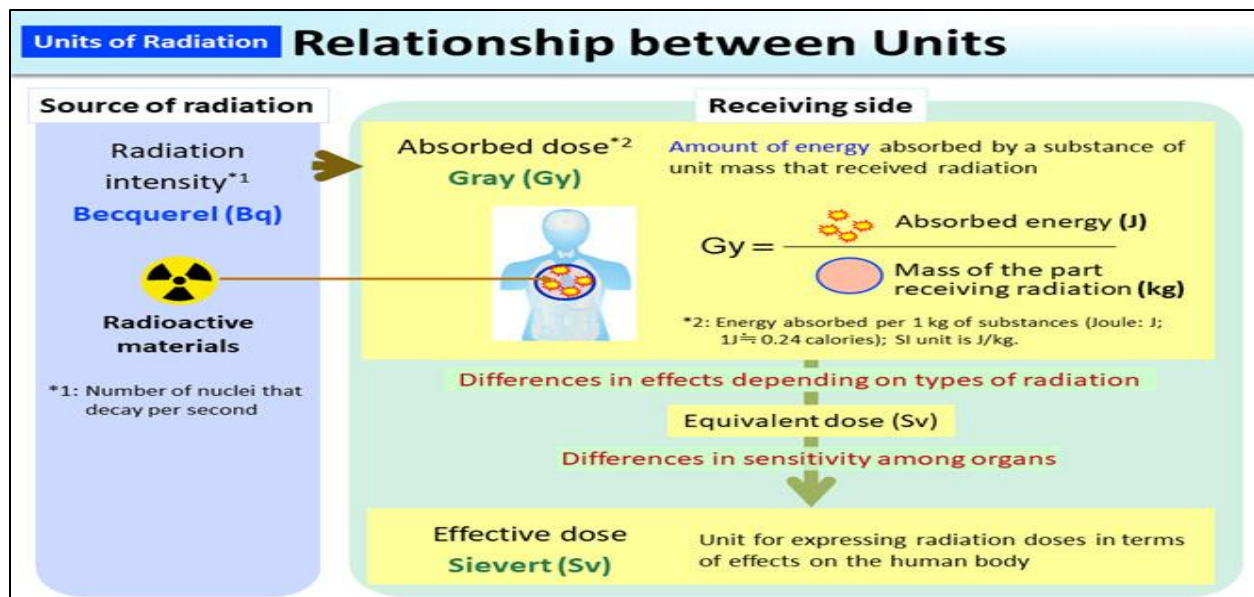


Fig.no. 2.7-- Relationship between radiation units

- ❖ The extent of effects on the human body varies depending on the types and energy quantities of radiation even if the absorbed doses are the same. Doses weighting health effects of respective types of radiation are equivalent doses (expressed in Sievert). The effective dose (expressed in Sievert) was developed for exposure management in radiological protection. In contrast to the equivalent dose, the effective dose weights differences in sensitivity among organs and tissues and sums them up to express the radiation effects on the whole body

## 6. Regulatory Dose Limits

- ❖ The Atomic Energy Regulatory Board (AERB) provides guidelines to ensure the safe use of ionizing radiation in India, aiming to protect both occupational workers and the general public from harmful effects of radiation. Natural background radiation contributes to a baseline exposure, but additional exposures from occupational or medical sources are regulated.
- ❖ According to AERB, the annual dose limits are as follows: for radiation workers, the maximum permissible dose is 20 mSv per year averaged over 5 years (with a maximum of 50 mSv in any single year); for the general public, it is 1 mSv per year; and for pregnant workers, the limit is 2 mSv for the remainder of the pregnancy after declaration.

- ❖ These limits are established to minimize stochastic effects and prevent deterministic effects of radiation, ensuring long-term safety for both workers and the public.
- ❖ The stipulated annual limit of radiation exposure for Occupational exposure / Public/Pregnant workers is mentioned in table 2.4

Category	Effective Dose	Lens of Eye	Skin	Extremities	Lifetime
<b>Occupational Workers</b>	20 mSv/year	20 mSv/year	500 mSv	500 mSv	1 Sv
<b>General Public</b>	1 mSv/year	15 mSv/year	50 mSv	-	
<b>Pregnant Workers (Fetus)*</b>	1 mSv (entire pregnancy)	-	-	-	

Table no. 2.4- Regulatory Dose Limits

**Once pregnancy is declared the equivalent dose limit to embryo/foetus shall be 1 mSv for the remainder of the pregnancy.** Dose limits for occupational exposure are 20 mSv/year averaged over 5 years, with no more than 50 mSv in any single year. (AERB)

## Regulatory Radiation Dose Limits and Medical Imaging Doses

- ❖ Regulatory dose limits are designed for planned, repeated exposures, not for one-time medical necessity.
- ❖ Medical imaging doses are **NOT** counted under public or occupational dose limits because they are medically justified exposures.
- ❖ Typical medical imaging effective doses include:
  - Chest X-ray (2 views): ~0.1 mSv
  - CT chest: ~6.1–7 mSv
  - PET scan (nuclear medicine): ~7 mSv
  - PET-CT scans can be higher (often 14–25 mSv when combining PET and CT components). These values are based on established dose catalogs used in practice and research.
- ❖ Thus, while individual imaging studies—especially CT and PET-CT—may approach or even exceed annual public dose limits, they remain well within occupational limits and are permitted because the diagnostic benefit outweighs the potential radiation risk, provided the principles of justification and ALARA are followed.

### Box 2.1 - Regulatory Radiation Dose Limits and Medical Imaging Doses

#### 7. Basic radiation protection techniques

- ❖ Radiation protection relies on three fundamental principles: Time, Distance, and Shielding, which together help minimize exposure to ionizing radiation:
  - **Time:** The dose received by an individual is directly proportional to the duration of exposure. Reducing the time spent near radioactive sources lowers the total absorbed dose. Minimizing unnecessary exposure is therefore essential in radiation work.
  - **Distance:** Increasing the distance from a radiation source reduces exposure according to the Inverse Square Law, where intensity decreases in proportion to the square of the distance. For example, direct contact with a 37 MBq vial of Sodium-22 results in an

exposure rate of about 150 mSv/hr, but at just 50 cm away, this drops to 0.06 mSv/hr. Maximizing distance from sources whenever possible significantly reduces dose.

- **Shielding:** Shielding involves the use of appropriate barriers to attenuate radiation and reduce the dose rate. The type and thickness of shielding material depend on the kind of radiation being encountered. Alpha particles travel only a short distance in air and require minimal or no shielding. Beta particles can be effectively blocked using low atomic number materials such as plastic or plexiglass; for example, a 3/8-inch plexiglass shield is recommended when handling P-32, as it also minimizes bremsstrahlung production (German for "braking radiation"). X-rays and gamma rays are more penetrating and require dense, high atomic number materials like lead. The required thickness is determined by the half-value layer (HVL), which is the thickness of material needed to reduce the radiation intensity by 50%. For example, shielding chromium-51 in the laboratory requires approximately 3.5 mm of lead to attenuate half of the emitted photons.

❖ **By applying time reduction, maximizing distance, and using effective shielding, radiation exposure can be controlled safely in both laboratory and clinical settings.**

## 7.1 Basic Radiation Protection Techniques – As Low as Reasonably Achievable (ALARA) Principle

❖ Radiation protection is essential in minimizing health risks associated with ionizing radiation exposure. A key concept in radiation safety is the ALARA principle, which stands for "**As Low as Reasonably Achievable.**" This principle guides the use of protective measures to reduce radiation doses to the lowest possible levels, considering economic and practical factors.

❖ The ALARA principle is built on three main strategies:

- **Time:** Minimize the time spent near radiation sources. Less time equals less exposure.
- **Distance:** Increase the distance from the radiation source. Radiation intensity decreases sharply with distance, following the inverse square law.
- **Shielding:** Use appropriate materials (e.g., lead, concrete, or water) to absorb or block radiation, depending on the type (alpha, beta, gamma, or neutron).

- ❖ In occupational settings such as hospitals, nuclear plants, and laboratories, ALARA is applied through procedures like monitoring radiation levels, using dosimeters, rotating staff and training personnel in radiation safety.

## **7.2 Implementation Strategies**

- ❖ Effective application of the ALARA principle requires structured radiation protection programs at workplaces, supported by the consistent use of personal dosimeters and appropriate protective equipment.
- ❖ Regular training, periodic monitoring, and continual optimization of operational procedures ensure that radiation doses remain as low as reasonably achievable, without compromising work efficiency or safety.

## **7.3 Regulatory Requirements in India**

- ❖ In India, the Atomic Energy Regulatory Board (AERB) incorporates ALARA as a foundational requirement in the licensing, operation, and inspection of all radiation facilities.
- ❖ The Bhabha Atomic Research Centre (BARC) further strengthens this framework by offering training, technical guidance, and practical tools to help institutions implement ALARA effectively.
- ❖ At the international level, the World Health Organization (WHO) advocates for the global integration of ALARA in medical imaging and radiotherapy practices to enhance patient and worker safety.

## **7.4 Optimization Approach:**

- ❖ The optimization process involves using cost–benefit analysis to determine the most reasonable and practical measures to minimize radiation exposure.
- ❖ This includes adopting technological upgrades, refining standard operating procedures, conducting periodic audits, and reviewing past incidents to prevent recurrence.
- ❖ Together, these strategies ensure that radiation exposure remains controlled and consistently optimized in accordance with ALARA principles.

### Take Home Message:

- ❖ Radioactive decay is a spontaneous process in which an unstable atomic nucleus transforms into a more stable one by emitting radiation ( $\alpha$ ,  $\beta$ , or  $\gamma$ ).
  - ❖ Each radioactive isotope decays at a predictable rate, measured by its half-life, the time taken for half the radioactive atoms in a sample to decay.
  - ❖ Decay follows an exponential pattern—after one half-life, 50% remains; after two, 25%; after three, 12.5%; and so on, never reaching absolute zero.
  - ❖ The concept of half-life is independent of external conditions like temperature or pressure and is critical in nuclear medicine, radiocarbon dating, and radioactive waste management.
  - ❖ Effective use of half-life data helps to determine radiation safety procedures, including safe handling times and storage requirements for radioactive materials.
  - ❖ Risk assessment must balance the benefits of radiation use with its potential harm, especially in medical and energy applications, industrial, agriculture, energy etc.
- 
- ❖ Radiation quantities and units: Exposure (R) measures ionization in air; absorbed dose (Gy) measures energy deposited in tissue; equivalent dose (Sv) accounts for radiation type and reflects biological risk; radioactivity (Bq) measures source activity.
  - ❖ Biological relevance: Exposure and radioactivity indicate potential for exposure, absorbed dose shows physical dose received, and equivalent dose directly relates to risk of biological effects.
  - ❖ Diagnostic imaging doses can exceed annual public dose limits, but are allowed due to clinical benefit.
  - ❖ By applying time reduction, maximizing distance, and using effective shielding, radiation exposure can be controlled safely in both laboratory and clinical settings.

## References (Adapted from)

- Hall, E. J., & Giaccia, A. J. (2018). Radiobiology for the Radiologist. Wolters Kluwer.
- Health Physics Society. (2022). "Radiation Types and Sources." [<https://hps.org>]
- World Health Organization (WHO). (2023). "Radiation Sources and Health Effects." [<https://www.who.int>]
- WHO. (2009). Communicating Radiation Risks in Paediatric Imaging
- IAEA. (2014). Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards (GSR Part 3)
- IAEA (2023). "Isotopes in Medicine and Industry." <https://www.iaea.org>
- IAEA. (2023). "Radioactive Decay." [<https://www.iaea.org>]
- IAEA (2023). "Understanding Radioactive Decay and Half-Life." [<https://www.iaea.org>]
- IAEA (2023). "Types of Ionizing Radiation." [<https://www.iaea.org>]
- IAEA (2023). "Ionizing Radiation." [<https://www.iaea.org>]
- IAEA (2023). "Natural and Artificial Radiation." [<https://www.iaea.org>]
- IAEA (2023). "Radiation Protection and Safety." [<https://www.iaea.org>]
- IAEA (2023). "Radiation Protection and Monitoring." [<https://www.iaea.org>]
- ICRP. (2023). Recommendations of the ICRP. [<https://www.icrp.org>]
- ICRP. (2023). Recommendations of the International Commission on Radiological Protection. [<https://www.icrp.org>]
- ICRP (2023). Radiological Protection: ICRP Publication 103. [<https://www.icrp.org>]
- BARC. (2021). Occupational Radiation Protection Training Manual
- AERB. (2011). Safety Code for Medical Diagnostic X-ray Equipment (AERB/RF-MED/SC-1 Rev. 2) and related safety guides
- AERB Directive No. 01/2011 - Under Rule 15 of the Atomic Energy (Radiation Protection) Rules 2004 Ref.No. No.CH/AERB/ITSD/125/2011/1507 dated April 27, 2011.
- Brian Nett, PhD "X-ray/CT radiation doses [7 anatomies] compared to background radiation for Radiologic Technologists/Radiographers." [<https://howradiologyworks.com/x-ray-ct-dose-to->

background/#:~:text=Cardiac%20CT%20Imaging%20Doses%20The%20doses%20for,doses%20are%20much%20lower%20for%20cardiac%20CT.]

- The Professional Version of the MSD Manuals (<https://www.msdmanuals.com/professional/multimedia/table/typical-radiation-doses?ruleredirectid=743>)
- Image:
  - Fig.no. 2.1 [adapted from Radiobiology for the Radiologist. Wolters Kluwer]
  - Fig.no 2.2 (New World Encyclopedia - Radioactive\_decay)
  - Fig.no 2.3 [adapted from IAEA (2023) "Radioactive Decay"]
  - Fig.no 2.4 [adapted from <https://www.eradimaging.com/course/756> Radiation Safety: A Growing Concern -Aimee J. Phillips, MS, RT(R)(M)(CV)(QM)]
  - Fig.no 2.5 ([https://www.utas.edu.au/\\_\\_data/assets/image/0005/638690/8.1.gif](https://www.utas.edu.au/__data/assets/image/0005/638690/8.1.gif))
  - Fig.no. 2.6 [Technical University of Crete <https://docplayer.gr/2172-Kefalaio-1-to-provlima-tis-poiotitas-aera-sto-esoteriko-ton-ktirion-triantafyllia-nikolaoy-m-sc-polytehneio-kritis.html>]
  - Fig.no. 2.7 (Booklet to Provide Basic Information Regarding Health Effects of Radiation- <https://www.env.go.jp/en/chemi/rhm/basic-info/1st/02-03-03.html>)

### **Suggested Reading**

- Hall, E. J., & Giaccia, A. J. (2019). Radiobiology for the Radiologist (8th ed.). Wolters Kluwer.
- Booklet to Provide Basic Information Regarding Health Effects of Radiation (5th edition) (MoE, Govt. of Japan) [<https://www.env.go.jp/en/chemi/rhm/basic-info/1st/03-02-04.html>]
- IAEA (2010). Radiation Biology: A Handbook for Teachers and Students ([https://www-pub.iaea.org/MTCD/Publications/PDF/TCS-42\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/TCS-42_web.pdf))

## Chapter 3

### Biological Effects of Ionizing Radiation

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand cellular effects of ionizing radiation
- Health effects based on organ radio-sensitivity
- Acute and chronic exposure effects on health

#### 1. Introduction

It has been more than one hundred years since Roentgen's discovery of X-rays. Radiation has been widely used for medical, industrial and other purposes. Hence the health effects of radiation have also been of concern to the public and researchers. There are two kinds of radiation: non-ionizing radiation and ionizing radiation. Non-ionizing radiation has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to remove electrons from atoms.

Ionizing radiation refers to energy capable of removing tightly bound electrons from atoms, thereby creating ions. It can alter cellular function and structure, particularly by damaging DNA. These effects have wide-ranging implications in healthcare, nuclear energy, and environmental health.

#### 2. Effect of ionizing radiation on the cell

- ❖ Ionizing radiation affects cells through two primary mechanisms: direct and indirect actions.
- ❖ In the direct pathway, the radiation particle or photon passes through a biological macromolecule—such as DNA, RNA, or proteins—causing immediate ionization or excitation. This can result in strand breaks, base damage, or structural alterations that compromise cellular function.
- ❖ In the indirect pathway, radiation interacts with intracellular water, leading to radiolysis and the formation of highly reactive free radicals. These free radicals—especially hydroxyl

radicals—diffuse through the cell and subsequently damage vital biomolecules. Together, these direct and indirect effects contribute to the biological consequences of radiation exposure.

## 2.2 Mechanism of Biological Damage

- ❖ **Linear Energy Transfer (LET):** LET is the energy lost by an ionizing particle per unit distance as it passes through a material. It quantifies the potential biological effects of radiation and depends on the charge and speed of the particle. High LET radiation, such as alpha particles, generally has a higher Relative Biological Effectiveness (RBE) compared to low LET radiation like beta particles or gamma rays.
- ❖ **Direct Action:** When radiation interacts directly with critical cellular components, such as DNA, it can disrupt cellular functions. This may impair the cell's ability to reproduce or cause chromosomal damage, potentially leading to cell death. High LET radiation primarily causes direct localized damage due to its dense ionization along the particle track.
- ❖ **Indirect Action:** Low LET radiation, such as beta particles and gamma rays, predominantly interacts with water molecules in the cell, which constitute most of its volume. This interaction leads to radiolysis of water, generating reactive free radicals like hydroxyl radicals ( $\text{OH}^\cdot$ ), which then damage DNA and other biomolecules. Indirect action accounts for most cellular damage from low LET radiation.

## 3. Possible Cellular Effects:

- ❖ Ionization can lead to molecular changes and to the formation of chemical species which may damage chromosome material. When ionizing radiation strikes the body, it randomly hits or misses millions of cells. For the cells which are not hit, the radiation simply passes through and no harm is done. If a cell is hit directly, the cell may be completely killed or, somewhat less likely, just damaged.
- ❖ Radiation Safety is concerned with cellular effects which result in damage to crucial reproductive structures such as the chromosomes and their components (e.g., genes, DNA, etc.).

- ❖ Radiation can produce several different types of damage such as small physical displacement of molecules or the production of ion pairs.
- ❖ If the energy deposited within a cell is high enough, biological damage can occur (e.g., chemical bonds can be broken and affected cells may be damaged or killed). Some of the possible results from cellular radiation interactions include:
  - **Repair** – In this the damaged cell can repair itself so no permanent damage is caused. This is the normal outcome for low doses of low linear energy transfer (LET), which is commonly encountered in the workplace.
  - **Mutation** - In a very small number of events, a damaged cell may exhibit a change in the cell's reproductive structure, allowing the cell to regenerate as a potentially pre-cancerous cell. Over a period of many years or decades, this may result in a full-blown, malignant cancer.
  - **Cell death** - The cell can die like millions of normal cells do naturally. The dead cell debris is carried away by the blood and a new cell is usually generated through normal biological processes to replace it.

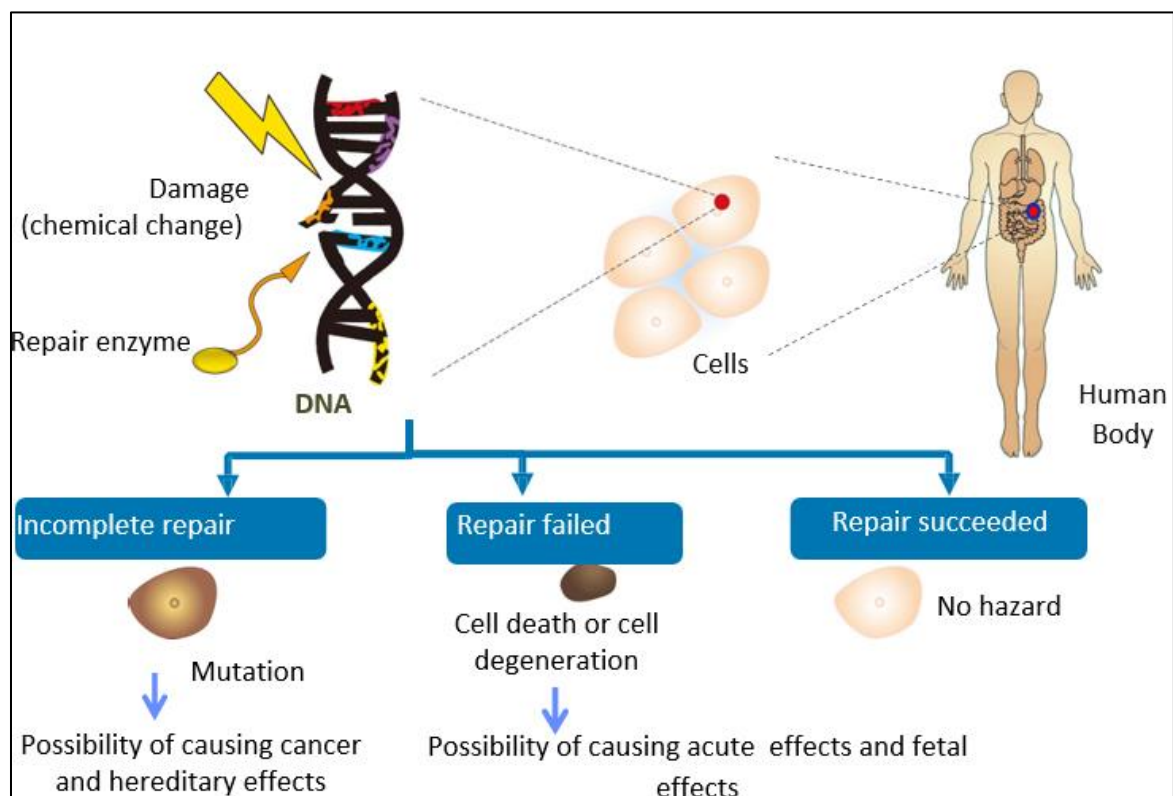


Fig.no. 3.1- Possible Results from Cellular Radiation Interactions

#### 4. DNA Damage and Repair

##### 4.1 Common types of DNA damage

- ❖ Radiation, especially ionizing radiation (e.g., X-rays, gamma rays), can interact with DNA directly or indirectly (through the generation of reactive oxygen species), leading to various types of DNA damage.

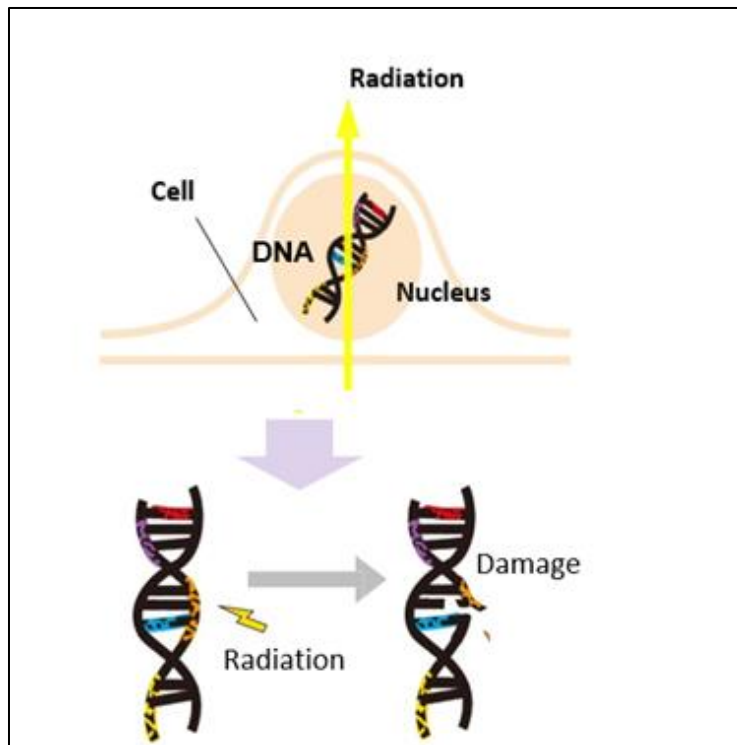


Fig.no. 3.2- Radiation Damage to DNA

- ❖ The common types include:

- **Base modifications methylation, oxidation:** Alterations to the chemical structure of the DNA bases which may cause mispairing during replication, leading to point mutations.
- **Mis-repairs mistakes in DNA synthesis:** Mis-repair refers to incorrect rejoining or processing of DNA damage, especially double-strand breaks (DSBs).
- **Double-stranded DNA breaks (DSBs):** Double strand breaks play a critical role in cell killing, carcinogenesis and hereditary effects. There are experimental data showing that:
  - initially-produced DSBs correlate with radio sensitivity and survival at lower doses
  - unrepaired or mis-repaired DSBs also correlate with survival after higher doses

- there is a causal link between the generation of DSBs and the induction of chromosomal translocations with carcinogenic potential
- **Cross-linked nucleotides Intrastrand, Interstrand covalent links:** These are the covalent links between DNA strands or between DNA and proteins, which hinder replication and transcription, making repair difficult.
- **Single-Strand Breaks (SSBs):** SSBs refer to the breakage of the phosphate backbone in one strand of the DNA double helix, which is, usually repaired efficiently by the cell's repair mechanisms.
- **Dimer Formation:** Although mainly caused by non-ionizing UV radiation, these lesions cause covalent bonding between adjacent thymine or cytosine bases, which can lead to distortion of the DNA helix and transcription errors.

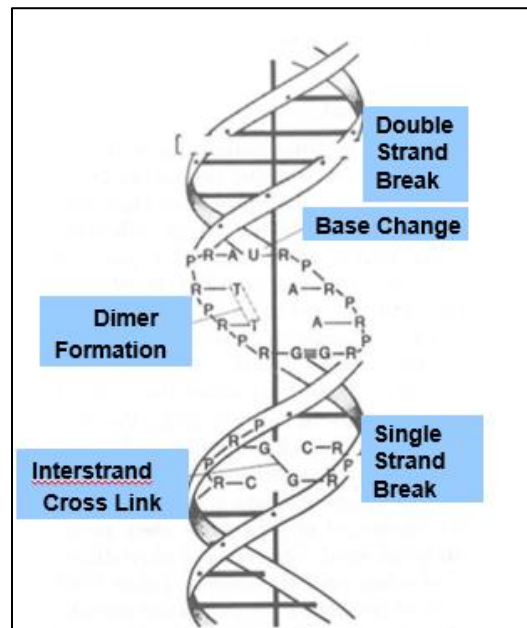


Fig.no. 3.3 –Types of DNA Damage

- ❖ The severity and type of DNA damage depend on the radiation dose, type of radiation, and cellular repair capacity. Ineffective repair may lead to mutations, cancer, or cell death.

#### 4.2 Repair of DNA:

- ❖ DNA repair is a multi-step process involving following broad steps:
  - An irregularity in DNA structure is detected

- The abnormal DNA is removed
  - Normal DNA is synthesized
- ❖ Common forms of damage have devoted repair enzymes for each of these processes. During this process of DNA repair, the cycling cells would normally arrest in one of the phases called the checkpoints. If the damage is in excess, the cells could undergo apoptosis or cell death. If there is a disrepair of DNA, there could be mutations.

### 4.3 Cellular DNA Repair Pathways

Cells have evolved multiple repair mechanisms to maintain genome stability after DNA damage caused by radiation. The repair pathway used depends on the type and complexity of the damage.

### 4.4 Types of Chromosomal Repair After Radiation-Induced Damage

- ❖ Depending on the efficiency and fidelity of the cellular repair machinery, chromosomal repair can be complete, incomplete, or misrepaired, leading to various biological consequences.
- ❖ **Complete Repair:** The broken chromosomal ends are correctly rejoined without any loss or gain of genetic information. The outcome of the repair is:
- Genome integrity is maintained
  - No long-term effects
  - Cell continues normal function
- ❖ **Incomplete or Partial Repair:** Improper or partial rejoining of broken chromosomal ends, leading to structural changes or loss of genetic material. The outcome of the repair is:
- Chromosomal Aberrations,
  - Chromothripsis (in high-dose or high-LET radiation) - Massive chromosomal rearrangements in a localized region.
  - Micronuclei Formation - a biomarker of genomic instability and radiation exposure associated with cancer development.
- ❖ **Failed Repair:** Breaks are left unrepaired causing apoptosis or cell degeneration. The outcome of the repair is: Apoptosis (cell death), Senescence (permanent growth arrest), Carcinogenesis, if the cell survives with mutations.

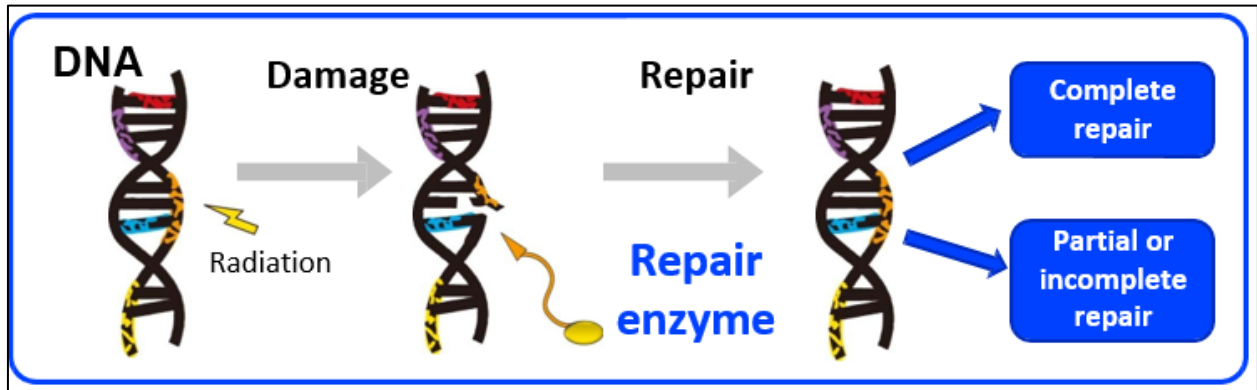


Fig.no. 3.4—Repair of DNA

❖ Different types of repair process exist in the cell to fix different types of damage in increasing order of complexity of the problem:

- Direct repair of specific modification
- Base excision repair missing or altered base
- Oligo nucleotide excision repair distortion of B-DNA (the most stable structure under ordinary cellular conditions) with damage on one strand
- Mismatch repair both bases are correct but the pairing is not
- Interstrand cross-link or double-stranded break repair both strands are damaged

#### 4.5 Cytogenetic consequence of radiation induced chromosome damage

❖ Ionizing radiation can induce various forms of DNA damage, particularly double-strand breaks (DSBs), which are the most severe. When DSBs occur in chromosomes, they can lead to a wide range of cytogenetic abnormalities, depending on the repair fidelity and the phase of the cell cycle during exposure.

❖ These are the structural changes in chromosomes observed under a microscope in metaphase cells formed due to misrepair of DSBs or incorrect rejoining of broken ends. These include:

- **Dicentrics (chromosomes with two centromeres):** Chromosomes with two centromeres, formed when broken chromosome fragments incorrectly join; unstable during cell division.
- **Ring chromosomes:** Chromosomes whose ends fuse to form a circle after breakage; may lose genetic material and are unstable.

- **Acentric fragments:** Chromosome pieces without a centromere; cannot segregate during cell division and are usually lost
  - **Translocations** - A translocation occurs when a segment of one chromosome breaks off and attaches to another chromosome. When translocations occur in germ cells they may lead to an increase in hereditary effects in the offspring. Symmetric translocations and small deletions are in general non lethal.
- ❖ **"Dicentrics and rings are hallmark aberrations in cells exposed to ionizing radiation."** Dicentrics and rings are "unstable" aberrations and are lethal to the cell and as a consequence they are not passed on to progeny.

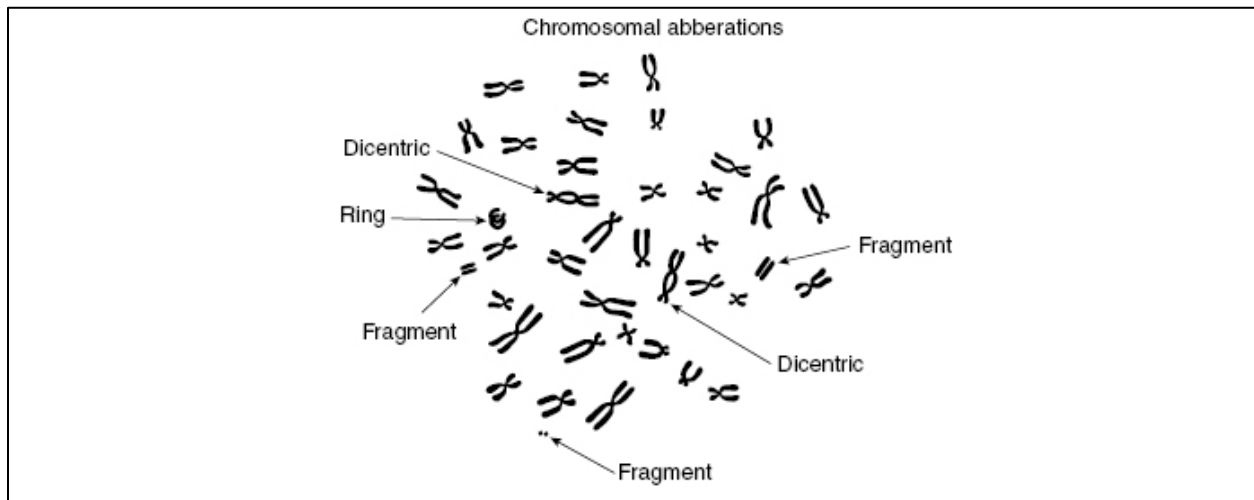


Fig. no.3.5-- Cytogenetic consequence of radiation induced chromosome damage

**4.6 Timeline and effects at cellular level:** Although the processes leading to radiation damage are complex, they are often considered as occurring in four stages.

- ❖ The initial **physical stage** lasts only a fraction ( $\sim 10^{-15}$ ) of a second. Radiation energy is deposited in the cell causing ionization.
- ❖ The **Physio-chemical stage** lasts about  $10^{-15}$  to  $10^{-12}$  seconds. Here the ions interact with other water molecules resulting in the production of  $H^+$ ,  $OH^-$ ,  $H\cdot$  and  $OH\cdot$ . While the  $H^+$  and  $OH^-$  are common in water, the other products, the free radicals  $H\cdot$  and  $OH\cdot$ , are chemically highly reactive. Another strong oxidizing agent produced is hydrogen peroxide,  $H_2O_2$ .

- ❖ The **chemical stage** lasts a few seconds. During this time period the reaction products interact with the important organic molecules of the cell. The free radicals and oxidizing agents may attack the complex molecules forming the chromosomes. These agents may attach themselves to a molecule or cause links in long chain molecules to be broken.
- ❖ The **biological stage** has a time scale which may last from tens of minutes to tens of years depending on the particular symptoms. These changes may affect a cell in a number of ways.

Stage	Duration	Process
<b>Physical</b>	$10^{-15}$ sec	Energy absorption, ionization
<b>Physio-chemical</b>	$10^{-6}$ sec	Interaction of ions with molecules and formation of free radicals
<b>Chemical</b>	Few seconds	Free radicals interact with DNA molecules
<b>Biological</b>	Few minutes to years	Cell death, mutation, change in genetic data in the cell

Table no.3.1 -- Timeline and effects at cellular level

- ❖ In as short a time as one-thousandth of a second after irradiation, DNA breaks and base damage occur. In a second after irradiation, DNA repair starts, and if repair fails, cell deaths and mutation occur within an hour to one day. It takes some time until such a reaction at the cell level develops into clinical symptoms at an individual level. This period is called the incubation period. Effects due to which symptoms appear within several weeks are called acute (early) effects, while effects that develop symptoms after a relatively long period of time are called late effects. In particular, it takes several years to decades until a person develops cancer. (Figure 3.6)

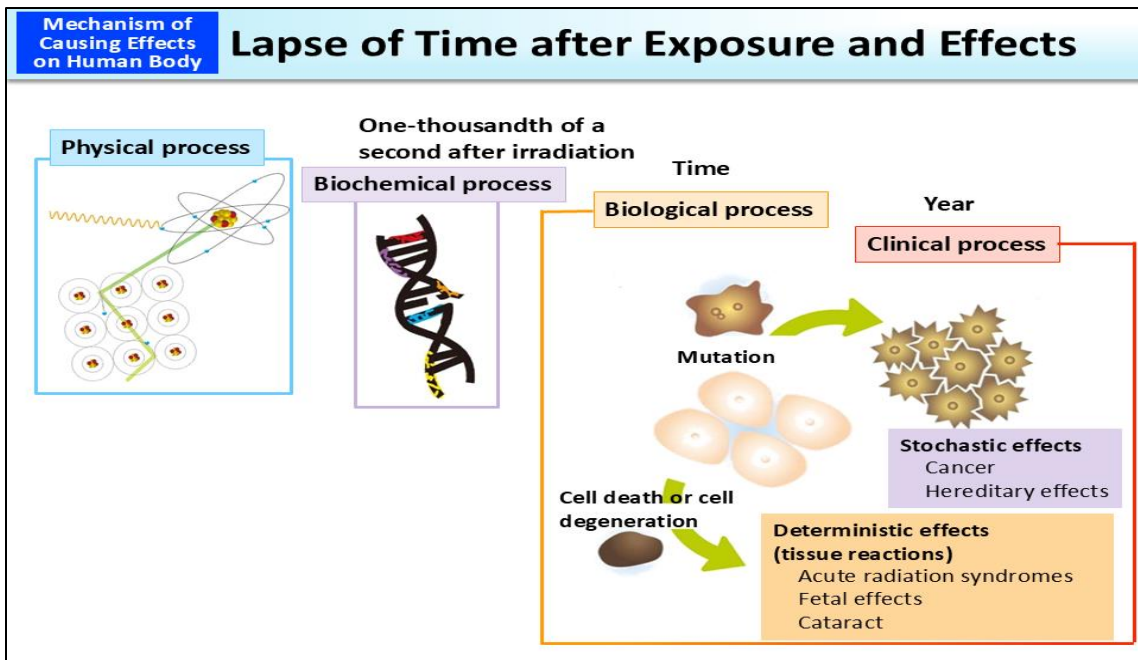


Fig.no. 3.6-- Lapse of Time after Exposure and Effects

## 5. Radio-sensitivity of Organs and Tissues

- ❖ Generally, the most radiosensitive cells are those which are:
  - rapidly dividing,
  - have a long dividing future (e.g., those in an early immature phase which are still dividing)
  - undifferentiated [i.e., are of an unspecialized type but will be capable of specialization at some future (adult) time].
- ❖ Examples of these highly radio-sensitive cells as given by the Law of Bergonie and Tribondeau (*which states, that the radio-sensitivity of a cell is directly proportional to reproductive rate and is inversely proportional to its degree of differentiation*) include immature blood cells, intestinal crypt cells, fetal cells, etc. Muscle and nerve cells are relatively insensitive to radiation damage.
- ❖ The radio sensitivity of various organs correlates with the relative sensitivity of the cells within the organ. Significant damage to these cells is often manifested by clinical symptoms such as decreased blood counts, radiation sickness, birth defects, etc., and, in the long term, increased cancer risk and cell survival curves.

### 5.1 Factors affecting body sensitivity to radiation:

- ❖ The extent of radiation-induced biological damage depends on several factors related to the tissue characteristics, radiation quality, and exposure conditions. The key factors are:
  - **Actively Dividing Cells:** Cells that proliferate rapidly, such as bone marrow, gastrointestinal epithelium, and reproductive tissues, are more radiosensitive.
  - **Rich oxygen saturation:** Tissues with higher oxygenation levels show greater radiation sensitivity due to the oxygen fixation effect, which makes DNA damage more permanent.
  - **Part of body exposed:** Sensitivity varies across organs. Critical organs like the gonads, bone marrow, and gastrointestinal tract are more vulnerable.
  - **Tissue volume exposed:** A larger tissue volume exposed to radiation results in more systemic effects and higher biological burden.
  - **Age of Individual:** Children and fetuses are more radiosensitive due to active cell division and organ development.
  - **General health status:** Poor nutrition, existing illness, or immune suppression reduces the body's ability to repair damage.
  - **Type of radiation / dose: High-LET radiation** (e.g., alpha particles) causes more severe and localized damage than low-LET radiation (e.g., X-rays).
  - **Time period over which exposure took place:** Fractionated or protracted exposure allows for biological repair, reducing severity compared to acute exposure.
- ❖ As shown in the figure 3.7, actively dividing cells that are less differentiated tend to show higher radiosensitivity. For example, hematopoietic stem cells in bone marrow are differentiated into various blood cells while dividing actively. Immature (undifferentiated) hematopoietic cells that have divided (proliferated) from stem cells are highly sensitive to radiation and die due to a small amount of radiation more easily than differentiated cells. As a result, the supply of blood cells is suspended and the number of various types of cells in blood decreases. In addition, the epithelium of the digestive tract is constantly metabolized and is also highly sensitive to radiation. On the other hand, nerve tissues and muscle tissues, which no longer undergo cell division at the adult stage, are known to be resistant to radiation.

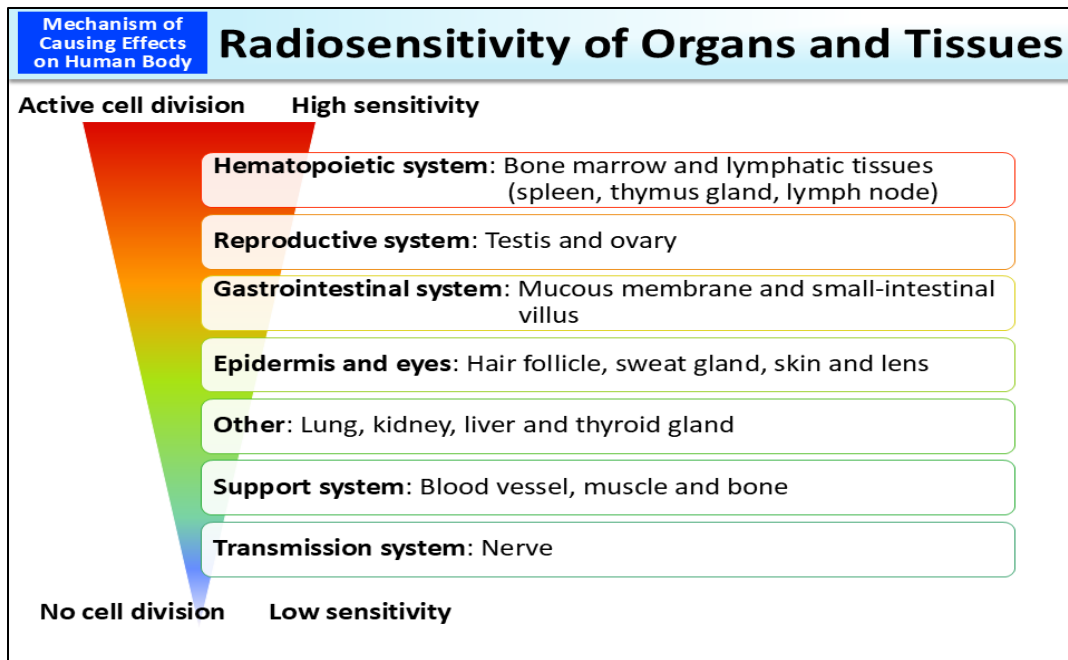


Fig.no. 3.7—Radiosensitivity of organs and tissues

## 5.2 Cellular Radiosensitivity

- ❖ Lymphocytes are very sensitive to ionizing radiation. As a consequence, lymphocytes serve as ideal biological dosimeters because they:
  - are very sensitive to radiation;
  - are readily available in routine blood samples;
  - circulate throughout the body;
  - are easily cultured and induced to divide in vitro;
  - respond consistently to ionizing radiation exposure by expressing chromosomal DNA damage in a dose-dependent manner.
- ❖ This characteristic is used for the purpose of biological dosimetry and lymphocytes counts may be used as a triage method if there are many persons purportedly exposed to ionizing radiation, as in a malevolent act.

### 5.3 Cell Cycle and Radio-sensitivity:

- ❖ The sensitivity of cells to ionizing radiation varies significantly across different phases of the cell cycle, primarily due to differences in DNA repair capacity, chromatin structure, and enzymatic accessibility.
- ❖ **Radio-sensitivity by Cell Cycle Phase:** The cell cycle is the sequence of events that a cell goes through to grow, replicate its DNA, and divide into two daughter cells. It consists of interphase (preparation for division) and the mitotic phase (cell division). Each phase has distinct features and functions.
  - **G<sub>0</sub> (Resting Phase)** is **highly radio-resistant**, wherein the resting cells, are not engaged in the active cell cycle, show very low radio-sensitivity due to low metabolic and replicative activity.
  - **First gap/ Growth (G<sub>1</sub>) Phase** is crucial for ensuring the cell is ready to accurately replicate its DNA in the S phase and proceed with cell division. It has **intermediate radio-sensitivity** as cells in G<sub>1</sub> phase have moderate sensitivity wherein repair is quick but error-prone.
  - **Gap 2/Mitosis (G<sub>2</sub>/M) Phase** represents the transition period between the G<sub>1</sub> phase, where the cell prepares for division, and the M phase (mitosis), where the cell actually divides. It is the **most radiosensitive**, wherein, the cells are highly sensitive to radiation damage in G<sub>2</sub> and mitotic phases. The condensed chromatin and inaccessibility of repair enzymes contribute to the poor repair of DNA lesions.
  - **Late Synthesis (S) Phase** is a crucial part of the cell cycle where DNA replication occurs and is the most radio-resistant, wherein the cells in late S phase are the most resistant due to efficient repair using homologous recombination (HR).

## 6. Pathogenesis of acute and late effects

### 6.1 ACUTE

- ❖ **Acute responses** occur primarily in tissues with rapid cell renewal, where cell division is required to maintain the function of the organ. Because many cells express radiation damage during mitosis, there is early death and loss of cells by radiation.
- ❖ Examples of early responding tissues are:
  - bone marrow

- gastrointestinal tract
  - skin
- ❖ In these tissues the acute radiation responses have been related to death of critical cell populations such as the stem cells in the -
- bone marrow
  - small intestine
  - basal layer of the skin
- ❖ Radiation-induced apoptosis has also been detected in many cells and tissues, such as:
- lymphoid
  - thymic
  - hematopoietic
  - spermatogonia
  - salivary gland
  - intestinal crypts
- ❖ In lymphoid and myeloid tissue, death by apoptosis plays an important role in the temporal response of these tissues to irradiation.
- ❖ In the crypts of the small bowel there is a fraction of stem cells that die by apoptosis, while other cells die by a mitosis-linked death.

## 6.2 LATE:

- ❖ **Late responses** tend to occur under normal conditions in organs whose parenchymal cells divide: a) infrequently (liver or kidney) or in b) rarely (central nervous system or muscle)
- ❖ Depletion of the parenchymal cell population due to entry of cells into mitosis, with the resulting expression of radiation damage and cell death, will thus be slow.
- ❖ Late responses also occur in tissues that manifest early reactions, such as skin/subcutaneous tissue and intestine, but the nature of these reactions (subcutaneous fibrosis, intestinal stenosis) is quite different from the early reactions.
- ❖ One common late reaction is the slow development of tissue fibrosis and vascular damage that occurs in many tissues and is often seen in cancer patients a number of years after radiation treatment.

## 7. Deterministic Effects of Radiation

- ❖ The deterministic effects have a well- defined threshold and increase in severity with dose.
- ❖ These effects include the acute radiation syndrome, characteristic of radiation sickness (leading to death), observed after whole body exposures to high doses, as well as non-lethal delayed effects like erythema (redness of the skin), sterility, cataract and hematological effects after whole body or partial body irradiation.
- ❖ Radiation teratogenesis (development of congenital abnormalities) is also considered to be a deterministic effect.
- ❖ Cell killing is the main process involved in the deterministic effects.
- ❖ As shown in the figure 3.8, even if some cells die due to exposure to a small amount of radiation, if tissues and organs can fully function with the remaining cells, clinical symptoms do not appear. When the amount of radiation increases and a larger number of cells die, relevant tissues and organs suffer temporary dysfunction and some clinical symptoms may appear. However, such symptoms improve when normal cells proliferate and increase in number. When cells in tissues or organs are damaged severely due to a large amount of radiation, this may lead to permanent cell damage or morphological defects.

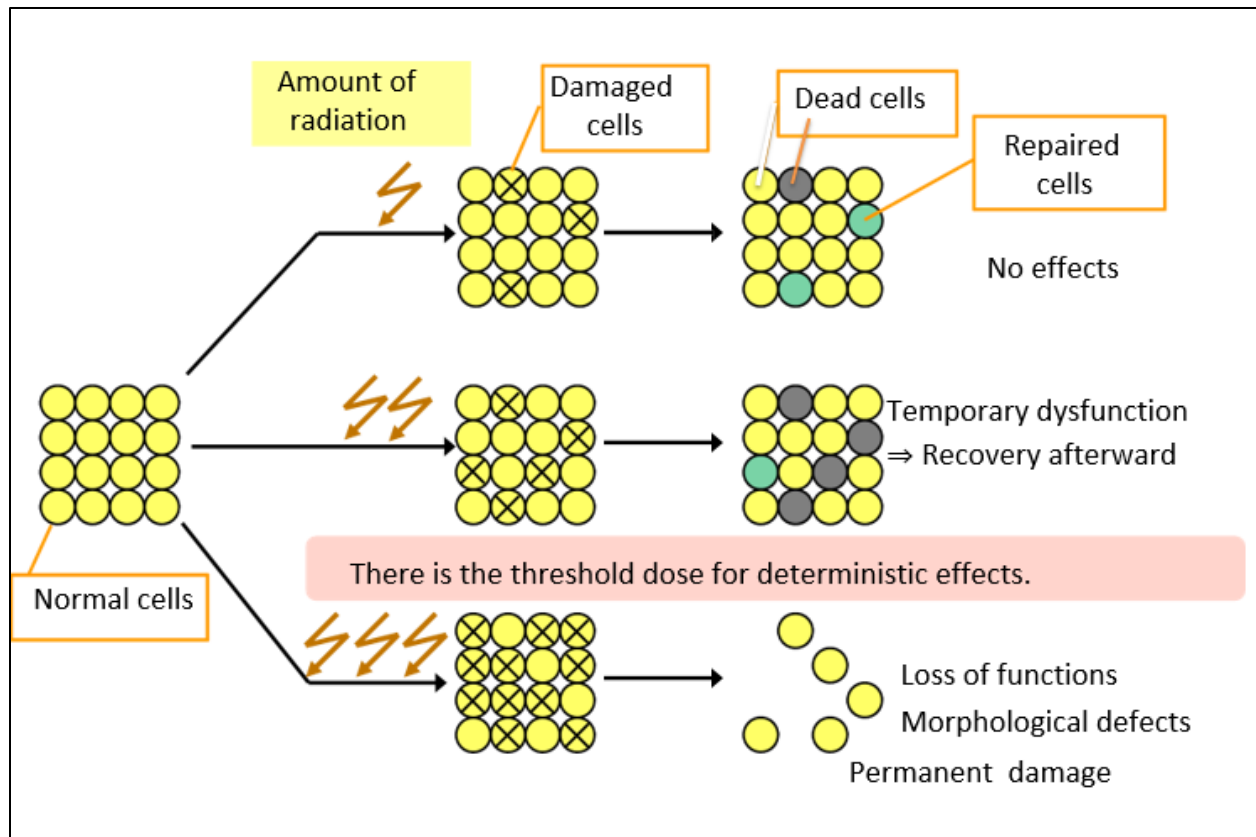


Fig.no. 3.8- Deterministic Effects

## 8. Stochastic Effects of Radiations:

- ❖ The stochastic effects are probabilistic, with no threshold. The effects of radiation at high doses and dose rates are reasonably well documented. A very large dose delivered to the whole body over a short time will result in the death of the exposed person within days. Much has been learned by studying the health records of the survivors of the bombing of Hiroshima and Nagasaki. We know from these that some of the health effects of exposure to radiation do not appear unless a certain quite large dose is absorbed. However, many other effects, especially cancers are readily detectable and occur more often in those with moderate doses.
- ❖ At lower doses and dose rates, there is a degree of recovery in cells and in tissues. However, at low doses of radiation, there is still considerable uncertainty about the overall effects.
- ❖ It is presumed that exposure to radiation, even at the levels of natural background, may involve some additional risk of cancer. However, this has yet to be established.

- ❖ To determine precisely the risk at low doses by epidemiology would mean observing millions of people at higher and lower dose levels. Such an analysis would be complicated by the absence of a control group which had not been exposed to any radiation.
- ❖ In addition, there are thousands of substances in our everyday life besides radiation that can also cause cancer, including tobacco smoke, ultraviolet light, asbestos, some chemical dyes, fungal toxins in food, viruses, and even heat. Only in exceptional cases is it possible to identify conclusively the cause of a particular cancer.
- ❖ In considering the radiation hazards from man-made sources, therapeutic exposures cannot be taken at par with the other exposures, as they are used as a clinical treatment for disease, in which a small number of persons get large doses capable of producing deterministic effects.
- ❖ Diagnostic x-rays are the major contributors to human exposure from artificial sources. In the industrial use of radiation and nuclear power production, the persons exposed to low doses far outnumber those who may receive high doses of radiation.
- ❖ Accordingly, the average dose delivered to a man from occupational and diagnostic exposures is not expected to produce any deterministic effect.
- ❖ The effects anticipated from such exposures are, therefore, stochastic in nature, which are both genetic and somatic.
- ❖ As shown in the figure 3.9, mutated cells are mostly repaired or eliminated but some survive and if their descendant cells are additionally mutated or the level of gene expression changes, the possibility of developing cancer cells increases. Proliferation of cancer cells leads to clinically diagnosed cancer (diagnosed by a doctor based on physical symptoms). Cells become cancerous as multiple mutated genes have accumulated without being repaired. Therefore, when assessing cancer-promoting effects, all doses that a person has received so far need to be taken into account.

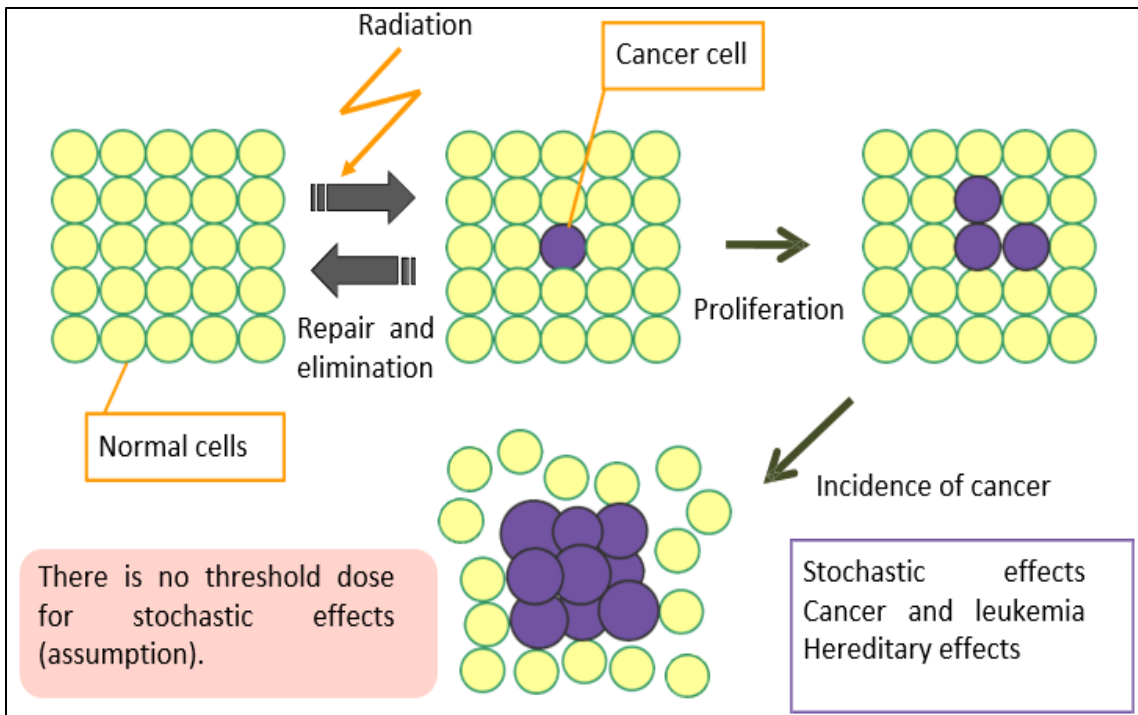


Fig.no. 3.9- Stochastic Effects

### 8.1 Types of Stochastic effects:

- ❖ **Genetic**-The effect is suffered by the offspring of the individual exposed. Mutation of the reproductive cells passed on to the offspring of the exposed individual. The Genetic Effect involves the mutation of very specific cells, namely the sperm or egg cells. Mutations of these reproductive cells are passed to the offspring of the individual exposed. Radiation is an example of a physical mutagenic agent. There are also many chemical agents as well as biological agents (such as viruses) that cause mutations. One very important fact to remember is that radiation increases the spontaneous mutation rate, but does not produce any new mutations. There is experimental evidence from animal studies that exposure to radiation can cause genetic effects. However, the studies of the survivors of Hiroshima and Nagasaki give no indication of this for humans. Again, if there were any hereditary effects of exposure to low-level radiation, they could be detected only by careful analysis of a large volume of statistical data. One possible reason why genetic effects from low dose exposures have not been observed in human studies is that mutations in the reproductive cells may produce such

significant changes in the fertilized egg that the result is a nonviable organism which is spontaneously aborted during the earliest stages of fertilization.

❖ **Somatic** - The effect is primarily suffered by the individual exposed. Since cancer is the primary result, it is sometimes called the Carcinogenic Effect.

• **Cancer Induction**

Somatic effects (carcinogenic) are, from an occupational risk perspective, the most significant since the individual exposed (usually the radiation worker) suffers the consequences (typically cancer). Radiation is an example of a physical carcinogen, while cigarettes are an example of a chemical cancer-causing agent. Viruses are examples of biological carcinogenic agents. The most important somatic stochastic effect of ionizing radiation is the induction of various types of cancer, some of which may take 20-30 years to appear, by which time other age-related changes and factors like personal habits and living conditions, are likely to camouflage the radiation effects. The long latent period between the exposure and the appearance of cancer and its radiation non-specificity make it difficult to find a direct correlation with the dose or even to establish radiation as the cause.

Sr. No.	Deterministic	Stochastic
1	High dose, short period	Low dose over long period
2	Immediate	After long latency
3	Threshold dose for effects	No threshold dose
4	Bound to happen over the threshold dose	By chance
5	Cell death or acute cell injury, loss of function of tissue/organ	Damage to cell – mutation and multiplication of mutant cells
6	<ul style="list-style-type: none"> <li>• Local radiation injury (erythema, burns)</li> <li>• Acute Radiation Syndrome</li> <li>• Abortion; Teratogenic effects, growth retardation (among in-utero exposed victims)</li> </ul>	<ul style="list-style-type: none"> <li>• Cancer</li> <li>• Childhood cancer (among in-utero exposed victims)</li> </ul>

Table no. 3.2 – Comparison Between Deterministic and Stochastic effects

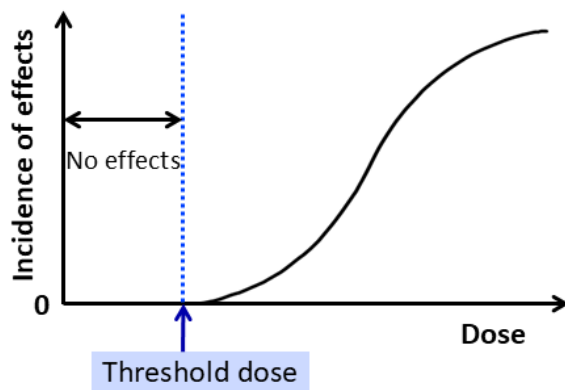
## Deterministic Effects (Tissue Reactions) and Stochastic Effects

### Deterministic effects (tissue reactions)

(Hair loss, cataract, skin injury, etc.)

A dose level, at which specific symptoms appear in 1% of the population exposed to the same dose of radiation, is defined as the threshold dose.

(2007 Recommendations of the International Commission on Radiological Protection (ICRP))



### Stochastic effects

(Cancer, leukemia, hereditary effects, etc.)

Effects of radiation exposure under certain doses are not clear because effects of other cancer-promoting factors such as smoking and drinking habits are too large. However, the ICRP specifies the standards for radiological protection for such low-dose exposures, assuming that they may have some effects as well.

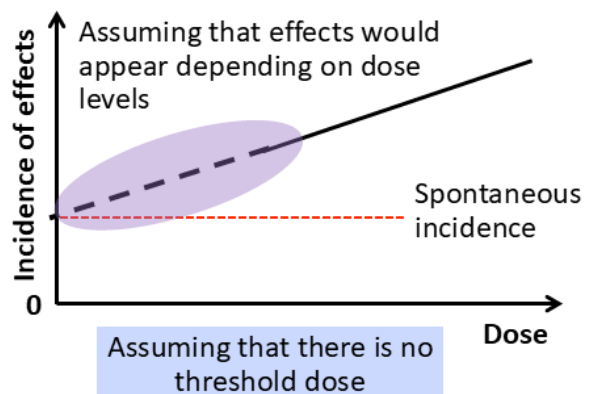


Fig.no. 3.10 —Deterministic and Stochastic Effects

- ❖ As shown in figure 3.10, one of the characteristics of the deterministic effects (tissue reactions) is the existence of the threshold dose, which means that exposure to radiation under this level causes no effects but exposure to radiation above this level causes effects. Radiation exposure above the threshold dose causes deaths or degeneration of a large number of cells at one time and the incidence rate increases sharply.
- ❖ On the other hand, in radiological protection, it is assumed that there is no threshold dose for stochastic effects. Under this assumption, the possibility that radiation exposure, even at extremely low doses may exert some effects can never be eliminated. It is difficult to epidemiologically detect stochastic effects due to radiation exposure at low doses below the range of 100 to 200 mSv, but the ICRP specifies the standards for radiological protection for

low-dose exposures, assuming that effects would appear depending on dose levels (linear dose-response relationship).

**9. Dose response relationship in deterministic effects**

- ❖ Radiation exposure at levels exceeding 100 mGy at one time may cause effects on the human body due to cell deaths. Organs highly sensitive to radiation are more likely to be affected with a small amount of radiation.
- ❖ As the testes in which cells are dividing actively are highly sensitive to radiation, even low doses of radiation at the levels of 100 to 150 mGy temporarily decrease the number of sperm and cause transient sterility.
- ❖ Bone marrow is also highly sensitive to radiation and lymphocytes in blood may decrease due to exposure to radiation even less than 1,000 mGy (= 1 Gy). However, these effects are naturally subdued.
- ❖ On the other hand, clinical symptoms may appear that require clinical care after exposure to radiation of more than 2,000 mGy at one time.

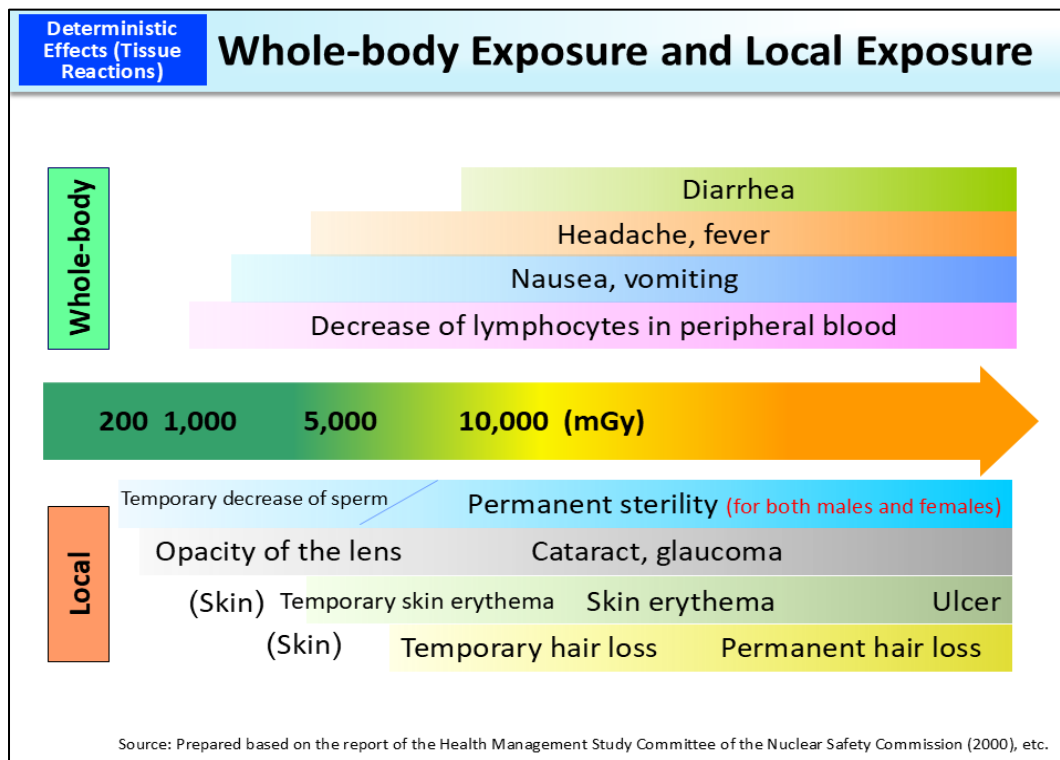


Fig.no.3.11 – Radiation Exposure – whole body and local

- ❖ The figure 3.11 explains the lapse of time after exposure effect , wherein, a single whole-body exposure to radiation exceeding 1 Gy (1,000 mGy) causes disorders in various organs and tissues, leading to complicated clinical developments. This series of disorders in organs is called acute radiation syndrome, which typically follows a course from the prodromal phase to the incubation phase, the onset phase, and finally to the convalescent phase or to death in the worst case.
- ❖ Figure 3.12, illustrates the prodromal symptoms that appear within 48 hours after the exposure, exposure doses can roughly be estimated. In the onset phase after the incubation phase, disorders appear in the order of hematopoietic organ, gastrointestinal tract, skin, and nerves and blood vessels, as doses increase. Disorders mainly appear in organs and tissues highly sensitive to radiation. In general, the larger the exposure dose, the shorter the incubation phase.
- ❖ Skin covers a large area of 1.3 to 1.8 m<sup>2</sup> of the whole body of adults. The epidermis, which is the result of gradual differentiation of basal cells that are created at the basal stratum, finally becomes a stratum corneum and is separated from the body surface as scurf. It is said to take approx. 20 to 40 days until basal cells move from the basal stratum to the skin surface, which means that two to more than four weeks are required for exposed subcutaneous cells existing in the stratum corneum to the basal stratum to come up to the skin surface. Therefore, skin erythema may appear immediately after exposure depending on radiation intensity, but skin injury generally appears after the lapse of a few weeks or more.

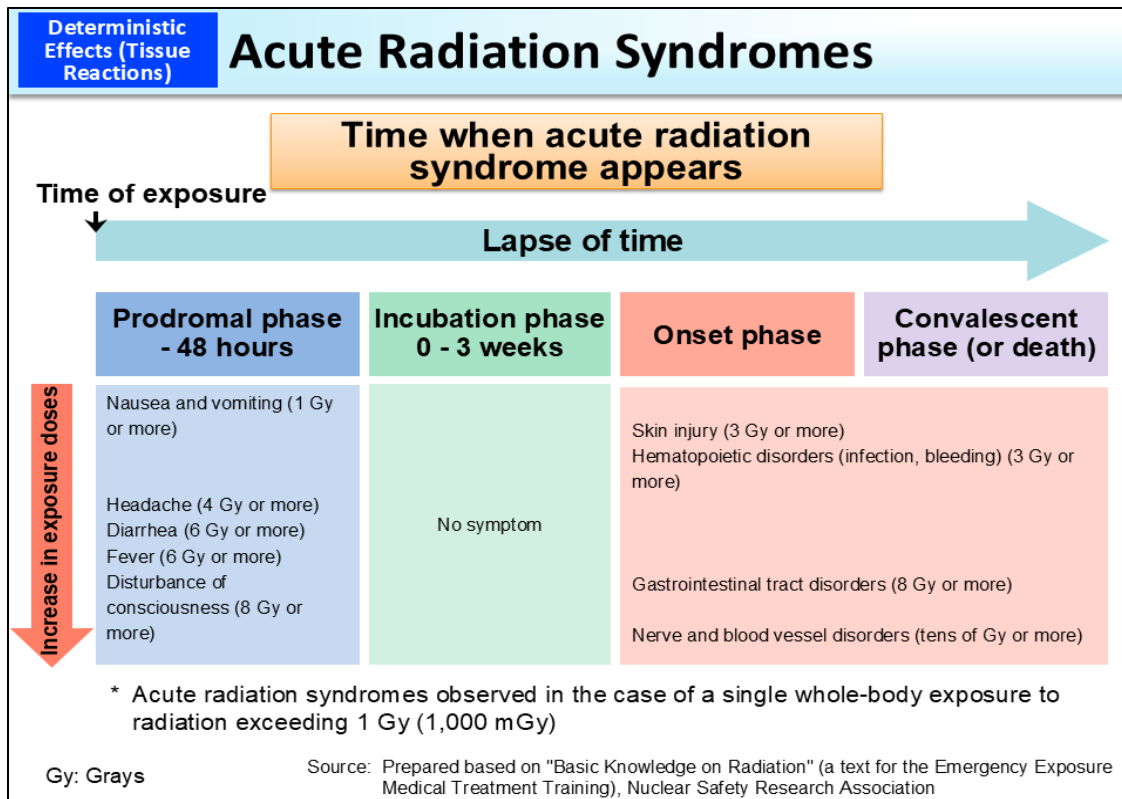


Fig. no. 3.12- Lapse of Time after exposure effect

**Deterministic Effects (Tissue Reactions)**

## Threshold Values for Various Effects

**Threshold acute absorbed doses of  $\gamma$ -rays**

Disorders	Organs/Tissues	Incubation period	Threshold value (Gy)*
Temporary sterility	Testis	3 to 9 weeks	Approx. 0.1
Permanent sterility	Testis	3 weeks	Approx. 6
	Ovary	Within 1 week	Approx. 3
Deterioration of hemopoietic capacity	Bone marrow	3 to 7 days	Approx. 0.5
Skin rubor	Skin (large area)	1 to 4 weeks	3 to 6 or lower
Skin burn	Skin (large area)	2 to 3 weeks	5 to 10
Temporary hair loss	Skin	2 to 3 weeks	Approx. 4
Cataract (failing vision)	Eyes	20 years or longer	Approx. 0.5

\* Threshold doses for symptoms with clear clinical abnormalities (doses causing effects on 1% of people)

Source: Prepared based on the 2007 Recommendations of the International Commission on Radiological Protection (ICRP), and ICRP Report 118 (2012)

Fig.no.3.13 – Threshold Values for Various Effects

- ❖ The figure 3.13 illustrates that the most sensitive organs include the testes. When the testes are exposed to  $\gamma$ -rays or other types of radiation exceeding 0.1 Gy (100 mGy) at one time, this may cause temporary sterility with a temporary decrease in the number of sperm, which is due to radiation damage to cells in the testes that create sperm. Also, if bone marrow is irradiated by more than 0.5 Gy (500 mGy) at one time, the hematopoietic function is impaired and a total number of blood cells may decrease. Some deterministic effects (tissue reactions), such as cataract, take several years to appear. The threshold dose for cataract had been set at 1.5 Gy, but the ICRP revised this value downward to approx. 0.5 Gy and set a new equivalent dose limit for the eye lens for occupational exposures.

#### **10. Doses necessary for temporary and permanent infertility**

- ❖ Ionizing radiation affects reproductive organs differently in males and females, and the severity of infertility depends on both dose and biological sensitivity.
- ❖ In males, exposure to 1.0 Gy can cause a temporary decline in sperm count, while doses around 1.5 Gy can induce temporary sterility.
- ❖ A dose of 2.0 Gy typically results in sterility lasting several years, whereas acute exposures of 5–6 Gy may lead to permanent sterility.
- ❖ In females, fertility is more sensitive to radiation; exposures between 0.65 and 1.5 Gy can significantly reduce fertility, and doses exceeding 6 Gy generally produce permanent sterility.
- ❖ Importantly, the threshold for sterility decreases with age in women, as older females have a smaller reserve of primary oocytes and therefore greater susceptibility to radiation-induced reproductive damage.

#### **11. Effects of in-utero exposure:**

- ❖ The principal effects of radiation on a fetus are:
  - fetal or neonatal death
  - malformations
  - growth retardation

- congenital defects
  - cancer induction
- ❖ Embryos in the pre-implantation stage are very radiosensitive and radiation damage inevitably will lead to:
- death of the conceptus
  - early spontaneous abortion
- ❖ Those embryos, however, which survive this stage, develop normally.

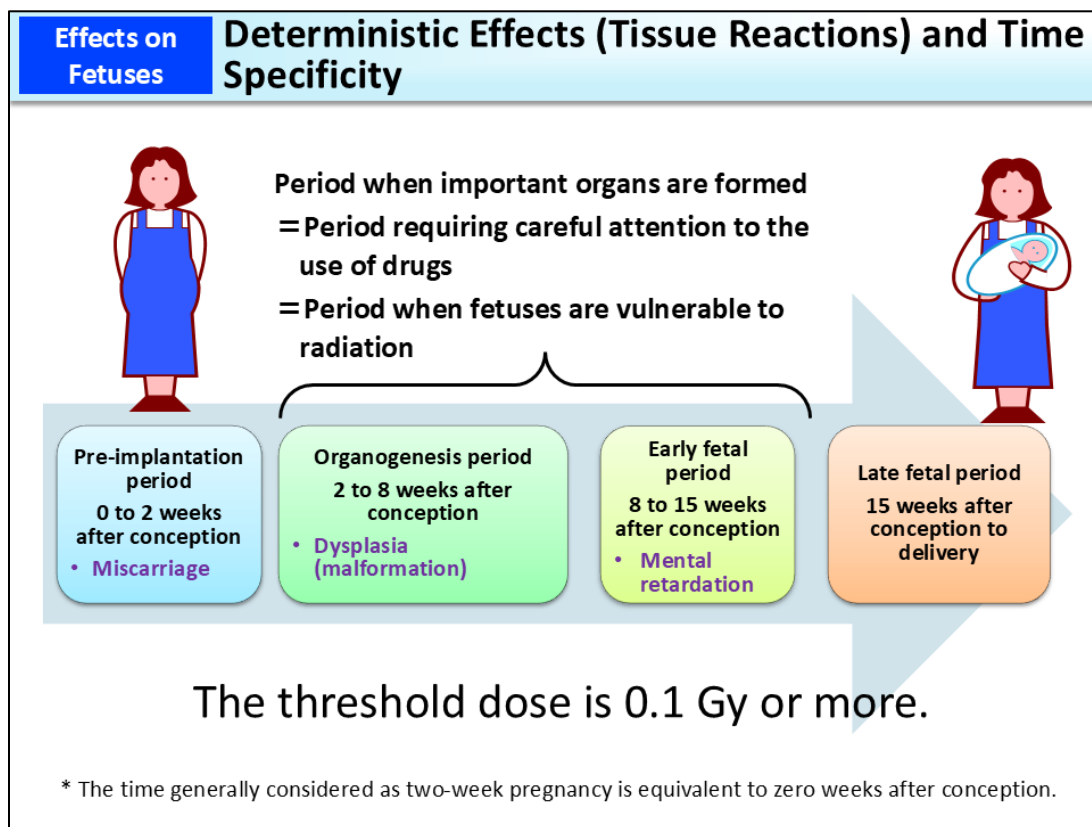


Fig.no. 3.14– Deterministic effects on Fetus

- ❖ As shown in the figure 3.14, deterministic effects include fetal effects for which the threshold dose is especially low. When a pregnant woman is exposed to radiation and radiation passes through her womb or radioactive materials migrate into her womb, her unborn baby may also

be exposed to radiation. It is known that fetuses are highly sensitive to radiation and incidence of effects has time specificity. Radiation exposure exceeding 0.1 Gy at an early stage of pregnancy (pre-implantation period) may lead to miscarriage. After this period, the possibility of miscarriage decreases, but radiation exposure exceeding 0.1 Gy during the period when important organs are formed (organogenesis period) may cause dysplasia (malformation). Radiation exposure exceeding 0.3 Gy during the period when the cerebrum is actively growing (early fetal period) poses risks of mental retardation.

- ❖ The period when fetuses are highly sensitive to radiation coincides with the period during which pregnant women are advised not to take drugs carelessly. During this period before the stable period, fetuses are vulnerable to both drugs and radiation. Fetal effects are caused by radiation exposure exceeding 0.1 Gy. Therefore, the International Commission on Radiological Protection (ICRP) states in its 2007 Recommendations that a fetal absorbed dose less than 0.1 Gy should not be considered as a ground for abortion. Exposure to 0.1 Gy of radiation is equivalent to exposure to 100 mSv of  $\gamma$ -rays or X-rays at one time. Incidentally, fetuses' exposure doses are not always the same as their mothers' exposure doses. Risks of stochastic effects such as cancer or heritable effects also increase depending on exposure dose levels.

### **11.1 Management When the Foetus is Exposed to Radiation**

- ❖ The findings of a probable threshold of 100 mGy will influence the advice to be given to pregnant women after a diagnostic radiology procedure
- ❖ According to the International Commission on Radiological protection (ICRP)- publication 84
  - **< 100 mGy:** No justification for pregnancy termination solely on radiation risk grounds.
  - **100–500 mGy:** Decision should be individualized, considering gestational age, clinical situation, and parental wishes.
  - **> 500 mGy:** High risk of deterministic effects; expert counselling strongly recommended.

## 11.2 Counselling

- ❖ Counselling for radiation exposure during pregnancy should begin by explaining the generally accepted threshold of **100 mGy**, below which significant fetal effects are unlikely.
- ❖ It is important to discuss potential physical risks in a balanced and reassuring manner, noting that the type and severity of effects—such as growth retardation, structural malformations, or cognitive impairment—depend strongly on the **gestational stage** at the time of exposure.
- ❖ Alongside the clinical information, counselling must also address the mother’s psychological concerns, helping to alleviate anxiety, correct misconceptions, and support informed decision-making through clear, empathetic communication.

## 11.3 Follow-up

Follow-up after radiation exposure during pregnancy should include scheduling appropriate prenatal imaging and arranging pediatric assessments after birth, based on the estimated fetal dose and gestational age at exposure. Continuous monitoring helps identify any developmental concerns early and provides reassurance to the parents. It is equally important to maintain clear and detailed documentation of dose estimates, counselling provided, and clinical decisions to ensure medico-legal clarity and support coordinated care throughout the pregnancy and postnatal period.

### Take Home Message:

- ❖ Biological effects of radiation are caused by the DNA damage due to ionizing radiation which may be direct or indirect.
- ❖ Cellular effects: Radiation damages DNA directly or via free radicals, causing cell death, mutation, or malfunction; high LET causes severe localized damage, low LET acts indirectly.
- ❖ Organ radiosensitivity: Highly sensitive – bone marrow, gonads, GI tract; moderately sensitive – skin, lung, kidney; resistant – brain, muscle, nerve.
- ❖ Lymphocytes are the most sensitive cells in circulating blood and one of the most sensitive cells in the organism to ionizing radiation.
- ❖ Exposure effects: Acute (high dose, short time) → radiation sickness, organ failure; Chronic (low dose, long time) → cancer, genetic mutations, long-term organ damage.
- ❖ Deterministic effect is acute effect threshold dependent; Stochastic effect is probabilistic in nature.
- ❖ According to the International Commission on Radiological Protection (ICRP)- publication 84, termination of pregnancy at fetal doses of less than 100 milli-gray (mGy) is not justified based upon radiation risk. At fetal doses between 100 and 500 mGy, the decision should be based upon the individual circumstances.

### References: (Adapted from)

- Hall, E. J., & Giaccia, A. J. (2019). Radiobiology for the Radiologist (8th ed.). Wolters Kluwer.
- UNSCEAR. (2000). Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation.
- ICRP. (2007). The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103.

- Bromet, E. J. (2012). Mental health consequences of the Chernobyl disaster. *Journal of Radiological Protection*, 32(1), N71-N75.
- IAEA. (2010). *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*.
- TEPCO. (2011). *Fukushima Nuclear Accident Analysis Report*.
- IAEA (2018) *Emergency Preparedness and Response*.
- National Council on Radiation Protection and Measurements (NCRP). (2020). *Population Monitoring and Medical Assessment After a Radiological Emergency*.
- U.S. Nuclear Regulatory Commission. (2016). *Radiation Protection and the NRC*
- [https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1798\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1798_web.pdf)
- <https://www.britannica.com/event/Fukushima-accident>
- IAEA (2006). *Chernobyl's Legacy: Health, Environmental and Socio-economic Impacts* (<https://www.iaea.org/sites/default/files/chernobyl.pdf>)
- WHO (2006). *Health Effects of the Chernobyl Accident and Special Health Care Programmes*
- UNSCEAR (2008). *Sources and Effects of Ionizing Radiation: Volume II*
- BARC & AERB *Emergency Response Guidelines*
- IAEA. *The Chernobyl Accident: Updating of INSAG-1, Safety Series No. 75-INSAG-7, 1992*.
- WHO (2006) *Health Effects of the Chernobyl Accident and Special Health Care Programmes, 2006*.
- UNSCEAR. *2008 Report Vol II: Effects of Radiation Exposure*.
- Andrews GA, et al. *Lymphocyte Depletion Kinetics for Dose Estimation, Health Physics*, 1981.
- *Booklet to Provide Basic Information Regarding Health Effects of Radiation (5th edition)* (MoE, Govt. of Japan) <https://www.env.go.jp/en/chemi/rhm/basic-info/1st/03-02-04.html>
- Hall, E. J., & Giaccia, A. J. (2019). *Radiobiology for the Radiologist (8th ed.)*. Wolters Kluwer
- Knoll, G. F. (2010). *Radiation Detection and Measurement (4th ed.)*. John Wiley & Sons.

- ICRP. (2007). The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37(2-4).
- Diagnostic Radiology Physics: a Handbook for Teachers and Students – chapter 20,40,38
- Bromet, E. J. (2014). Emotional consequences of nuclear power plant disasters. Health Physics, 106(2), 206–210. <https://pmc.ncbi.nlm.nih.gov/articles/PMC3898664/>
- Bromet, E. J. (2012). Mental health consequences of the Chernobyl disaster. Journal of Radiological Protection, 32(1), N71–N75
- Streffer, C. et al., Radiation effects on the embryo and fetus, Ann. ICRP 33(1-2), 2003.
- UNSCEAR. (2000). Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, Volume I
- UNSCEAR (2000). Sources and Effects of Ionizing Radiation, Volume II, Annex G: Biological Mechanisms of Radiation Action.
- ICRP (2000), Pregnancy and Medical Radiation — Publication 84, Ann. ICRP 30(1)
- WHO (2006). Health effects of the Chernobyl accident and special health care programmes.  
[https://iris.who.int/bitstream/handle/10665/43447/9241594179\\_eng.pdf?sequence=1](https://iris.who.int/bitstream/handle/10665/43447/9241594179_eng.pdf?sequence=1)
- IAEA (2010). Radiation Biology: A Handbook for Teachers and Students, TECDOC-1151, Module 6. ([https://www-pub.iaea.org/MTCD/Publications/PDF/TCS-42\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/TCS-42_web.pdf))
- IAEA, Radiation Protection Principles
- AERB. Fundamentals of Radiological Protection, Government of India.
- AERB Training Manual on Radiobiology
- AERB Radiation Safety Manual,2021
- BARC Newsletter No. 342, Cytogenetic Studies in Radiation Workers

- BARC. Radiobiology & Health Physics Training Manual, BHP Division, Trombay.
- BARC Training Manual on Radiation Effects
- Image:
  1. Fig.no. 3.1,3.2, 3.4 [National Council on Radiation Protection and Measurements (NCRP),2008]
  2. Fig.no 3.3 (Travis, 1989; courtesy of Dr Raymond E Meyn and Dr Ron Humphrey, M D Anderson cancer Center)
  3. Fig.no 3.5 (<https://radiologykey.com/7-radiation-damage-and-repair-of-cells/>)
  4. Image: Fig.no. 3.6,3.7,3.8,3.9.3.10,3.11,3.12,3.13,3.14 (Booklet to Provide Basic Information Regarding Health Effects of Radiation)

### **Suggested Reading**

- Hall, E. J., & Giaccia, A. J. (2019). Radiobiology for the Radiologist (8th ed.). Wolters Kluwer.
- Booklet to Provide Basic Information Regarding Health Effects of Radiation (5th edition) (MoE, Govt. of Japan) [<https://www.env.go.jp/en/chemi/rhm/basic-info/1st/03-02-04.html>]
- IAEA (2010). Radiation Biology: A Handbook for Teachers and Students ([https://www-pub.iaea.org/MTCD/Publications/PDF/TCS-42\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/TCS-42_web.pdf))

## Chapter 4

### Overview of Radio-Nuclear Emergencies

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand the various types and causes of radiation accidents.
- Analyze past nuclear accidents and derive key learnings.

#### 1. Introduction

- ❖ Radio-nuclear emergencies encompass situations involving the release or potential release of radioactive materials and the consequent exposure to ionizing radiation. These emergencies can be accidental, stemming from system failures or human errors, or intentional, such as acts of terrorism or warfare. Accidents rarely occur due to an isolated reason. Most of the time it is a combination of factors like equipment failure, human error, natural causes etc. culminating in an accident.

#### 2. Radiation Accident

- ❖ According to the IAEA, a radiation accident is an event that leads to unintended exposure of people or the environment to ionizing radiation. Radiation accident includes both Nuclear and Radiological accidents.

##### 2.1 Radiation Accidents in Nuclear Power Plants

- ❖ Nuclear power is a vital source of low-carbon energy but comes with inherent risks associated with radiation. History has demonstrated that accidents in nuclear power plants (NPPs),

though rare, can have serious consequences for human health, the environment, and public trust.

❖ Reasons for such accidents, most of the time are a combination of factors like equipment failure, human error, natural causes etc. culminating in an accident. Some of these are enumerated as under:

- No proper safety evaluation
- Poor/no education and lack of training,
- No Quality assurance programme
- Not having or/and not following SOP
- Not following Regulatory guidelines
- Management pressure (real or perceived) to continue work even when safety systems were inoperable or deficient,
- Poor maintenance programme or none at all, leading to a reduction in layers of safety, and non-investigated false alarms leading to persons ignoring warning systems.
- Environmental challenges (Fukushima accident)

## **2.2 International Nuclear Event Scale (INES)**

❖ The International Nuclear and Radiological Event Scale is a tool for communicating the safety significance of nuclear and radiological events to the public.

❖ As shown in the figure 4.1, INES has been developed by the IAEA and Organization for Economic Co-operation and Development (OECD) / Nuclear Energy Agency (NEA), this scale is logarithmic – that is, the severity of an event is about ten times greater for each increase in level of the scale, which ranges from Level 1 (anomaly) to Level 7 (major accident). This classification considers:

- Radiological impact on people and the environment
- Degradation of defense-in-depth
- Failure of safety provisions

- ❖ Events without safety significance are rated as Below Scale/Level 0. Events that have no safety relevance with respect to radiation or nuclear safety are not rated on the scale.



Fig.no. 4.1 -- International Nuclear Event Scale (INES)

### 2.3 Criteria for Classification:

❖ The International Atomic Energy Agency (IAEA) and the Atomic Energy Regulatory Board (AERB) have established dose thresholds to help authorities determine when a radiological or nuclear event qualifies as an accident requiring formal emergency response. These thresholds indicate levels of exposure likely to produce measurable biological effects and guide rapid protective actions.

- **Whole-Body Dose > 250 millisievert (mSv):** Exposure above this level can cause systemic effects, such as a temporary decrease in blood cell counts. This is significantly higher than normal occupational limits and signals a serious overexposure incident.
- **Skin or Extremity Dose > 6,000 mSv:** Localized high doses to the skin or limbs can lead to radiation burns, ulceration, and long-term tissue damage, even if the overall whole-body dose remains lower.
- **Other Tissue or Organ Dose (External) > 750 mSv:** Significant exposure to a specific organ, such as the eyes or thyroid, can result in organ-specific injuries, including cataracts or thyroid dysfunction, independent of whole-body exposure.

**Note: Meeting or exceeding any of these thresholds triggers the need for immediate assessment, medical intervention, and activation of emergency response protocols.**

## 3. Types of Accidents

**3.1 Reactor or Criticality:** Accidents involving uncontrolled nuclear chain reactions or reactor instability, often due to procedural errors, design flaws, or equipment failure. (Refer Box 4.1 for examples)

❖ **Windscale, England (1957) - Reactor Fire**

- **Cause:** Fire in a graphite-moderated reactor used for plutonium production.
- **Impact:** Release of radioactive iodine-131; widespread contamination.
- **Lessons:** Need for proper reactor heat management and air filtration systems.

❖ **Three Mile Island, USA (1979) - Partial Core Meltdown**

- **Cause:** Cooling system failure and operator error.
- **Impact:** Partial meltdown; no significant health effects, but major public concern.
- **Lessons:** Importance of real-time monitoring, control systems, and emergency training.

❖ **Chernobyl, Ukraine (1986)– Explosion and Fire**

- **Cause:** Unsafe reactor design and deviation from safety protocols.
- **Impact:** INES Level 7 event; widespread radioactive fallout across Europe.
- **Lessons:** Catalyst for IAEA Conventions on nuclear safety and early warning.

❖ **Tokai-Mura, Japan (1999)– Criticality Accident**

- **Cause:** Improper manual mixing of enriched uranium.
- **Impact:** Two fatalities and hundreds exposed.
- **Lessons:** Emphasized safety in non-reactor nuclear facilities and strict procedural controls

Box 4.1 – Examples of Reactor or Criticality Accidents

**3.2 Orphan (Mishandled/ Lost/ Stolen) Sources:** These accidents occur when radioactive materials—typically used in industrial, medical, or research settings—are lost, stolen, or improperly disposed of, and later handled by unaware individuals, often resulting in serious radiation injuries or death.

❖ **Mayapuri incident, Delhi in 2010**

- **Cause:** Orphan source (Cobalt-60) sold as scrap and handled unknowingly.
- **Impact:** One fatality, several radiation injuries.
- **Lessons:** Strengthened source tracking, licensing, and disposal practices.

Box 4.2- Examples of Orphan (Mishandled/ Lost/ Stolen) Sources

**3.3 Mis-administration of Medical Radiation**

❖ Mis-administration of medical radiation refers to errors in the delivery of radiation during diagnostic or therapeutic procedures. These errors can result in overexposure or underexposure to patients, potentially causing acute radiation injuries, delayed complications, or treatment failure.

❖ Common contexts where mis-administration may occur:

- Radiological Emergencies – Errors in emergency settings due to haste or equipment malfunction.
- Industrial Radiography – Unshielded or improperly handled sources causing unintentional exposures.
- Orphan Sources – Lost, stolen, or unregulated radioactive sources used unknowingly in medical or public settings.
- Radiotherapy – Incorrect calibration, planning errors, or software issues (e.g., Panama 2000 incident).
- Nuclear Medicine – Wrong radiopharmaceutical or incorrect dosage administered to patients.

- Diagnostic Imaging – Excessive repeated scans or technical errors (CT, fluoroscopy) exposing patients unnecessarily.
- Pilferage – Theft of radioactive sources, especially in unsecured facilities.
- Transportation – Accidental exposure during transit due to package leakage or misidentification.
- Terrorism – Use of radioactive materials to intentionally expose populations (e.g., dirty bombs).
- Nuclear Power Plants – Exposure due to procedural lapses or during maintenance involving radioactive materials.
- Nuclear Warfare – Large-scale radiation injuries due to deliberate use of nuclear weapons.

#### ❖ Panama (2000)

- **Cause:** Human error or equipment malfunction during diagnostic or therapeutic procedures. Example: In Panama (2000), a software configuration error during radiotherapy planning led to patients receiving overdoses.
- **Impact:** Radiation injuries to patients, including burns, organ damage, and increased cancer risks. In the Panama case, 28 cancer patients were overexposed, and at least 8 died as a result of radiation-induced complications.
- **Lessons:** Radiation safety training for healthcare professionals, implementation of rigorous Quality Assurance (QA) and peer-review protocols, regular audits, maintenance, and calibration of medical radiation equipment, adoption of error reporting systems and international best practices.

Box 4.3 – Examples of Mis-administration of Medical Radiation Accidents

- ❖ Table 4.1 enlists examples of accidents involving industrial or orphan radioactive sources (e.g., Iridium-192, Cesium-137, Cobalt-60) that were lost, stolen, mishandled, or not properly shielded, leading to lethal radiation exposure.

Year & Location	Isotope Involved	Impact	Key Points
1981 – Oklahoma, USA	Unknown	1 fatality	Worker received lethal dose from an industrial radiography source.
1984 – Morocco	16.3 Curie (Ci) of Iridium-192	8 fatalities	Source was taken home and handled over several days.
1987 – Goiania, Brazil	1375 Ci of Cesium-137	4 fatalities, 250+ contaminated	Abandoned radiotherapy source in scrap; led to one of the worst radiological accidents.
1993 – Tallinn, Estonia	Cesium-137	1 fatality	Scrap metal worker unknowingly exposed to radiation source.
2000 – Bangkok, Thailand	750 Ci of Cobalt-60	3 fatalities	Orphan source from decommissioned teletherapy unit; sold as scrap metal.

Table no.4.1 - Fatal Source Accidents

- ❖ **Lessons Learned:**

- Need for strict control and disposal of radioactive sources.
- Importance of public awareness, scrap yard monitoring, and emergency response preparedness.

- ❖ Table 4.2 enlists examples of incidents occurred during radiotherapy, diagnostic imaging, or nuclear medicine procedures due to overexposure, misadministration, or equipment malfunction, resulting in multiple patient deaths.

Year & Location	Type	Fatalities	Cause
1968 – Wisconsin, USA	Radiotherapy	1 fatality	Calibration error

<b>1975 – Ohio, USA</b>	Radiotherapy	10 fatalities	Incorrect dose delivery
<b>1980 – Texas, USA</b>	Radiotherapy	7 fatalities	Malfunctioning treatment unit
<b>1986 – Texas, USA</b>	Nuclear medicine	2 fatalities	Mis-administered radiopharmaceuticals
<b>1990 – Spain</b>	Radiotherapy	10 fatalities	Software configuration error
<b>1992 – Indiana, USA</b>	Radiotherapy	1 fatality	Incorrect treatment protocol
<b>1996 – Costa Rica</b>	Radiotherapy	3–7 fatalities	Dose miscalculation in cancer patients

Table no. – 4.2- Fatal Medical Accidents

❖ **Lessons Learned:**

- Quality Assurance (QA) programs in radiation medicine are essential.
- Mandatory staff training, equipment checks, and incident reporting are critical to prevent recurrence.

**5. Case Study of Nuclear Power Plant Accidents - Chernobyl Nuclear Accident**



Fig. no.4.2-Reactor 4 site in weeks following the explosion, with damaged structures and fallout signs

## ❖ Chernobyl Nuclear Accident (1986)

### Cause:

- RBMK reactor design flaws (positive void coefficient, no containment).
- Operator errors during a late-night safety test; safety systems disabled.
- Poor safety culture and delayed recognition of the accident severity.

### Impact:

- Explosion of graphite fire released massive radioactive material ( $\approx 400\times$  Hiroshima).
- 31 immediate deaths, 134 ARS cases; long-term rise in thyroid cancer and leukemia.
- Severe psychological impact: anxiety, PTSD, stigma.
- Large-scale evacuation (116,000 initially; 210,000 later).
- Creation of the 30 km Exclusion Zone; long-term environmental contamination.
- Global reforms in nuclear safety and emergency preparedness.

### Lessons Learnt:

- Strengthen safety culture, operator training, and adherence to protocols.
- Improve reactor design, shutdown systems, and containment structures.
- Ensure timely evacuation, iodine prophylaxis, and food/water controls.
- Maintain transparent communication and international cooperation (IAEA).
- Provide long-term health monitoring and mental health support.

Box 4.4 – Summary of Chernobyl Nuclear Accident (1986)

## 5.1 Introduction

On April 26, 1986, at 01:00 Hrs. the Chernobyl Nuclear Power Plant in Pripyat, then part of the Soviet Union (now Ukraine), suffered the world's worst nuclear disaster.

## ❖ What Happened?

During a late-night safety test in Reactor No. 4, operators shut off key safety systems and simulated a power outage. Due to design flaws in the RBMK\* reactor and operator error, the reactor became unstable. A sudden power surge caused a massive explosion, blowing off the reactor's lid and releasing deadly radioactive materials into the atmosphere.

*\*The Soviet-designed RBMK (Reaktor Bolshoy Moshchnosty Kanalny, high-power channel reactor) is a water-cooled reactor with individual fuel channels and using graphite as its moderator. It is also known as the light water graphite reactor (LWGR).*

## ❖ The Fallout

- The explosion released at least 400 times more radiation than the Hiroshima bomb.
- The fire burned for 10 days, spreading radioactive isotopes like iodine-131, cesium-137, and strontium-90 across Europe.
- 31 immediate deaths occurred due to the explosion and acute radiation syndrome.
- Large areas of Ukraine, Belarus, and Russia remain contaminated.
- The region around the reactor, known as the Chernobyl Exclusion Zone, is still uninhabited

## ❖ Response & Legacy

- Deployment of liquidators (workers, soldiers, and firefighters) to contain the disaster. 2,00,000 in the first phase and subsequently 8,00,000.
- The nearby city of Pripyat (population ~50,000) was evacuated 36 hours later.
- A concrete sarcophagus was built in 1986 to contain the radiation. A more durable steel shelter was completed in 2016.
- The Chernobyl disaster led to global reforms in nuclear safety and emergency preparedness.
- It remains a chilling reminder of the consequences of poor safety culture, secrecy, and inadequate design in nuclear operations.

## **5.2 Chernobyl Nuclear Disaster Management Measures**

### **❖ Immediate Measures:**

- First aid, decontamination (removal of contaminated clothing), and administration of Potassium Iodide (KI) were initiated to reduce iodine uptake by the thyroid.
- Protective actions were taken by on-site responders and medical teams.

### **❖ Triage:**

- Approximately 500 individuals were screened for symptoms of radiation exposure and contamination.
- Medical assessment prioritized those with potential acute radiation syndrome (ARS).

### **❖ Hospitalization:**

- 237 individuals were hospitalized, mostly plant workers and first responders
- 134 were diagnosed with ARS, with 28 fatalities occurring within the first few weeks due to high radiation doses

### **❖ Evacuation:**

- Within 36 hours of the accident, 116,000 people were evacuated from a 30 km radius around the reactor. The town of Pripyat was evacuated to Slavutich.
- Over the following year, an additional 210,000 people were relocated from contaminated areas.

### **❖ Prophylaxis:**

- Potassium Iodide (KI) was administered as a thyroid-blocking agent. 1.6 million children received KI prophylaxis. A total of 5.3 million people were given KI in the affected regions.

## **5.3 Health and Mental Health Impact – Chernobyl Disaster**

### **❖ Acute Radiation Syndrome (ARS):**

- 134 cases of confirmed ARS among workers and first responders.
- 28 early fatalities occurred within the first 3 months (due to high-dose exposure).
- By 2006, 19 additional deaths occurred among this group, though none conclusively linked to radiation exposure.

❖ **Impact on Mental Health:**

- According to the World Health Organization, mental health consequences were among the most significant public health issues post-disaster.
- Widespread anxiety, depression, post-traumatic stress disorder (PTSD), and social stigma were prevalent among evacuees, cleanup workers, and affected communities.
- Fear of long-term health effects—even among those with low or no exposure—contributed to reduced well-being and quality of life.

❖ **Thyroid Carcinoma:**

- The Chernobyl disaster released a significant amount of radioactive iodine isotopes, particularly Iodine-131 (<sup>131</sup>I), into the environment. These isotopes were rapidly absorbed by the thyroid gland, especially in children, due to their active iodine metabolism. Between 1990 and 2000, over 1,800 cases of thyroid cancer were reported among 18 million young people (children and adolescents) living in the most contaminated areas of Belarus, Ukraine, and Russia.
- Other factors contributing to the increased rate of childhood thyroid cancer around Chernobyl are enumerated as under:
  - High uptake of I-131 by thyroid tissue in growing children.
  - Moderate to severe iodine deficiency
  - Late iodine prophylaxis (or thyroid blocking in many villages and towns not evacuated)
  - Active screening (ultrasound, fine needle biopsy) manifesting also the occult cases
  - Awareness (parents request more thyroid examinations of their children than before)
  - Contaminated milk and leafy vegetables were a major source of internal exposure.

- ❖ **Elevated Leukemia Rates After Chernobyl:** There is a tendency for elevated leukemia rates among individuals who received significant radiation doses while working at the Chernobyl site in 1986 and 1987, primarily liquidators (cleanup workers). The statistically significant increase in leukemia incidence has been reported only among Russian cleanup workers. These findings are based on long-term epidemiological monitoring and cohort studies conducted post-accident.

❖ **Other Physical Health Effects:**

- Cataracts were more frequently observed in individuals who received the highest radiation doses (UNSCEAR, 2008)
- No increased rates of congenital abnormalities: 14 healthy children were born to ARS survivors within 5 years of the accident (WHO, 2006).

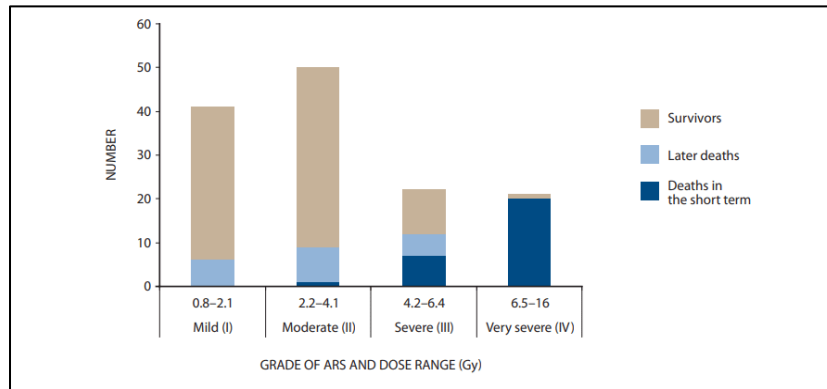


Fig. no.4.3 - Outcome for Patients with ARS

**5.4 Medical Management of ARS (Chernobyl Context)**

❖ **Dose Estimation:**

- Radiation dose estimation in acute exposure scenarios relies on both clinical features and laboratory indicators.
- One widely used method is Andrew’s Nomogram, based on lymphocyte depletion kinetics, which assists in early triage and rapid dose assessment.
- By evaluating the rate of lymphocyte decline within the first 24–48 hours, clinicians can estimate the severity of exposure—a rapid fall in lymphocyte count strongly suggests a high-dose event.
- This approach provides valuable guidance for determining the urgency and intensity of medical interventions, especially in mass-casualty or resource-limited settings.

❖ **Additional tools:**

- Several supplementary tools support radiation dose assessment and help refine clinical decision-making.
- Early skin reactions, such as erythema or blistering, provide visible indicators of localized exposure.

- The hematologic profile, particularly findings like lymphopenia or neutropenia, offers valuable information on systemic dose effects.
- More specialized techniques include cytogenetic dosimetry, which analyzes chromosomal aberrations to estimate absorbed dose with high accuracy.
- Additionally, Electron Spin Resonance (ESR) or Electron Paramagnetic Resonance (EPR) can be used to assess radiation-induced signals in biological materials such as teeth or fingernails, providing another reliable method for biological dosimetry.

❖ **Patient Management:**

- Management of patients exposed to significant radiation doses requires meticulous supportive care and infection control.
- Individuals with Acute Radiation Syndrome (ARS), especially those receiving doses greater than 2 Gy, are at high risk of infection due to bone marrow suppression and immune compromise.
- Such patients are often placed in reverse isolation wards, where strict environmental controls—including UV air sterilization—help minimize microbial exposure. Before admission to general hospital units, patients should undergo initial decontamination to prevent the spread of radioactive material.
- Adequate nutritional support is essential; meals may be provided as normal or pressurized cooked food, the latter produced under high pressure using systems like autoclaves or retort processing to ensure sterility and safety for immunosuppressed individuals. Together, these measures form a comprehensive approach to protecting vulnerable patients and optimizing recovery.

❖ **Infection Control:**

- In patients with Acute Radiation Syndrome (ARS), particularly those exposed to doses exceeding 2 Gy, bone marrow failure leads to severe immune suppression, making infection control a critical component of management.

- Broad-spectrum **antibiotics**, such as cephalosporins and aminoglycosides, are used to address both gram-negative and gram-positive bacterial infections.
- **Antifungal agents** like amphotericin B or fluconazole are administered prophylactically or therapeutically in neutropenic patients who are at high risk for fungal infections.
- **Antivirals**, including acyclovir and ganciclovir, play an important role in preventing or treating viral reactivation, such as herpesvirus or cytomegalovirus (CMV).
- Additionally, **intravenous immunoglobulins (IVIG)** may be provided to offer passive immunity and enhance host defenses in severely immunocompromised individuals.
- Together, these interventions form a comprehensive strategy to mitigate infectious complications and improve survival outcomes in ARS.

#### ❖ **Hematological Support:**

- Radiation doses exceeding 2–4 Gy commonly lead to hematopoietic syndrome, making timely hematological support essential for patient survival.
- Management includes transfusion of **packed red blood cells** to correct anemia and improve oxygen delivery, and **platelet transfusions**—either autologous or donor-derived—to manage bleeding associated with thrombocytopenia.
- In several ARS cases, including those documented after the Chernobyl accident, **granulocyte colony-stimulating factor (G-CSF)** was used to stimulate neutrophil recovery and reduce the risk of life-threatening infections.
- For patients sustaining doses greater than 6 Gy, where bone marrow aplasia becomes irreversible, **bone marrow transplantation (BMT)** may be considered.
- Following the Chernobyl disaster, 13 patients underwent BMT, but only two survived, with most deaths resulting from severe infections, graft failure, or multi-organ dysfunction.
- Overall, the acute radiation syndrome death toll at Chernobyl was 29, with the primary causes of death being septicemia, multi-organ failure, and profound bone marrow suppression.

## 5.5 Post-Chernobyl Agricultural & Foodstuff Countermeasures

### ❖ Changes in Cropping Practices

- Following radioactive fallout, large agricultural zones were contaminated (notably with isotopes like Iodine-131, Cesium-137, and Strontium-90). To mitigate uptake by plants and reduce human exposure:
- Deep plowing and soil inversion were performed to bury contaminated topsoil.
- Crop rotation was modified—leafy vegetables and root crops (which absorb radionuclides easily) were replaced with cereal crops and oilseeds, which accumulate less radioactivity.
- Soil additives such as potassium fertilizers and lime were used to reduce uptake of Cesium (Cs-137) and Strontium (Sr-90) by crops.

### ❖ Milk and Meat – Veterinary Measures

- Cattle and sheep grazing on contaminated pastures accumulated radionuclides, especially Cesium-137 and Strontium-90, in milk and meat.
- Radiogardase (Prussian Blue) was administered to livestock. This compound binds cesium in the gastrointestinal tract and reduces absorption, thus lowering Cs-137 levels in milk and meat products.
- In some regions, milk was destroyed or processed into less-contaminated products (e.g., butter or cheese).
- Slaughtering of animals was delayed until contamination levels decreased.

### ❖ Foodstuff Industry

- Monitoring and decontamination of food products was intensified.
- Export restrictions were placed on contaminated foodstuffs.
- Industrial processing methods (washing, boiling, fermenting) were evaluated to reduce radionuclide content in processed foods.
- Food bans were imposed in highly contaminated regions (e.g., parts of Belarus, Ukraine).

## 5.6 Lessons Learnt and Methods to Limit Exposure

❖ Major nuclear accidents such as the Chernobyl disaster have emphasized the need for rapid and effective measures to minimize radiation exposure among affected populations. Key lessons learned include the importance of early warning systems, timely decision-making, and public communication strategies. The following are core methods used to limit exposure to radioactive materials:

### ❖ Evacuation

- Objective: Rapidly move populations away from contaminated areas to prevent both external and internal radiation exposure.
- Lesson: Timely evacuation significantly reduces dose and health risks. Delays can lead to unnecessary exposure, particularly in high-dose zones.

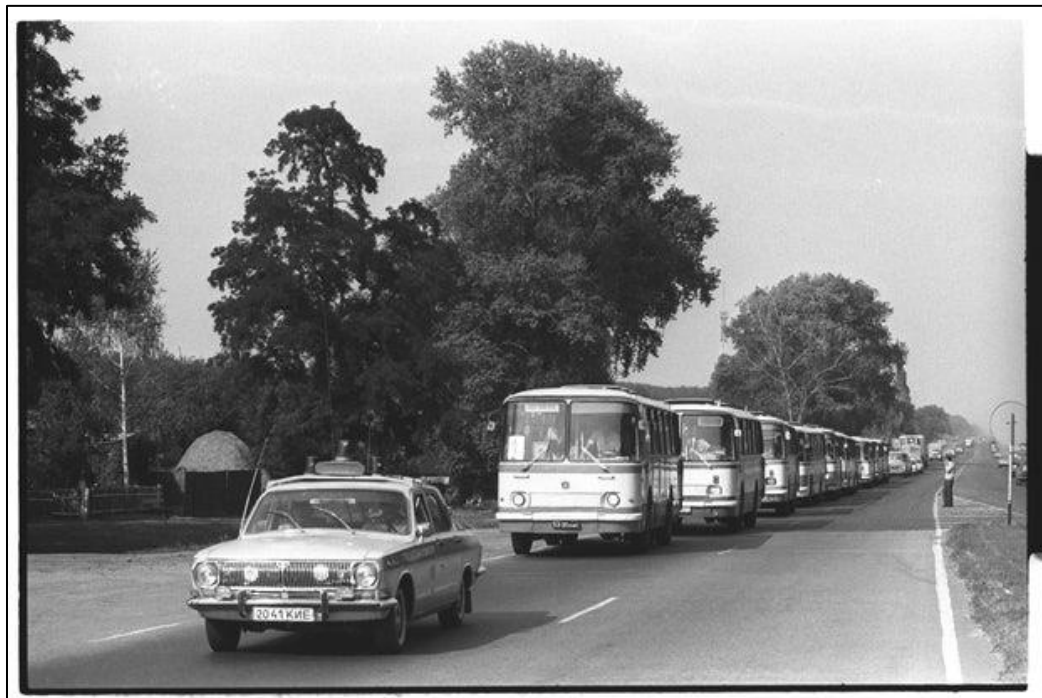


Fig. no. 4.4 -- The evacuation of 47,000 inhabitants of Prip'yat, in 1,200 buses and 200 trucks, only took a few hours. Locals believed they would be returning several days later. Instead, it became a ghost town.

#### ❖ **Sheltering**

- Objective: Instructing people to stay indoors, close windows and doors, and turn off ventilation systems to limit inhalation of airborne radioactive particles.
- Lesson: Effective as an immediate short-term action, especially when radioactive plumes are still dispersing.

#### ❖ **Control of Contaminated Food and Water**

- Objective: Prevent ingestion of radionuclides such as Iodine-131 and Cesium-137 through contaminated milk, vegetables, or meat.
- Lesson: Surveillance and regulation of the food chain are critical. Restricting or banning consumption of contaminated local produce helps reduce internal dose.

#### ❖ **Blocking Radionuclide Uptake (Stable Iodine Prophylaxis)**

- Objective: Administration of stable iodine (KI) tablets can block uptake of radioactive iodine by the thyroid gland.
- Lesson: Timing is critical — most effective if administered before or shortly after exposure.

#### ❖ **Relocation**

- Objective: Permanent or long-term movement of people from areas with persistent contamination where dose levels exceed safety thresholds.
- Lesson: While necessary in some cases, relocation has long-term psychological, social, and economic impacts and must be managed with proper support systems.

### **5.7 Chernobyl 30 Years On – Epidemiological Findings**

- ❖ Recent long-term studies have provided new insights into the health impacts of the Chernobyl nuclear disaster. While the full extent of late health effects is still under investigation, several significant patterns have emerged:

- **Leukemia risk in liquidators:** An increased incidence of leukemia has been observed among the Chernobyl liquidators (cleanup workers), particularly those exposed to higher radiation doses during 1986–1987. Statistically significant excess found mainly among Russian liquidators.
  - **Breast cancer in contaminated districts:** Elevated incidence of **pre-menopausal breast cancer** has been reported in women residing in highly contaminated areas of Belarus and Ukraine. This suggests a potential association between low-to-moderate radiation exposure and breast cancer risk.
  - **Cataracts and cardiovascular diseases:** New evidence suggests possible low-dose radiation effects on the risk of cataract formation and cardiovascular conditions, such as ischemic heart disease. These outcomes were not previously considered radiation-induced at low doses.
- ❖ However, these findings must be interpreted with caution due to numerous confounding factors, such as socioeconomic conditions, lifestyle changes, psychological stress, and lack of precise dose estimates.

## 6. Case Study of Nuclear Power Plant Accidents - Fukushima Dai-ichi Nuclear Power Station Event

### ❖ Fukushima Dai-ichi Nuclear Power Station Event

#### Cause:

- Massive 9.0 earthquake and 15 m tsunami (11 March 2011).
- Tsunami flooded backup generators → total power loss.
- Cooling failure → core meltdowns in Units 1–3.
- Hydrogen explosions caused structural damage.
- Resulted in release of radioactive material to air and sea.

#### Impact:

- >150,000 evacuated; no acute radiation deaths.
- Worker exposures increased; few exceeded 100–250 mSv.
- Major psychological stress and evacuation-related indirect deaths.
- Environmental contamination by I-131 and Cs-137; long-term doses generally low.

#### Lessons learnt:

- Strengthen flood/tsunami protection and ensure multiple power backups.
- Improve emergency communication, command systems, and preparedness.
- Balance evacuation with actual radiation risk; ensure clear public communication.
- Maintain long-term monitoring of workers, environment, and communities.

Box 4.5 – Summary of Fukushima Dai-ichi Nuclear Power Station Event (2011)



Fig.no. 4.5 - Before and after: Fukushima Daiichi Nuclear Power Plant

## 6.1 Introduction

- ❖ On 11<sup>th</sup> March, 2011, a nuclear accident occurred at the Fukushima Dai-ichi Nuclear Power Plant in Japan, triggered by a natural disaster [9.0 magnitude earthquake struck off the northeast coast of Japan, followed by a massive tsunami (up to 14–15 meters high) that reached the coast within 45 minutes], disrupting the cooling systems and leading to core meltdowns in three reactors, hydrogen explosions, and the release of radioactive material into the environment. Over 150,000 people were evacuated, and long-term effects are still under study.

## 6.2 How It Happened?

- **Earthquake Impact:**
  - The plant automatically shut down (scrammed) all three operating reactors (Units 1, 2, and 3).
  - Backup diesel generators activated to maintain reactor cooling.
- **Tsunami Damage:**
  - The tsunami overwhelmed the plant's seawall and flooded the generator buildings, knocking out backup power.

- Loss of cooling led to overheating of the reactor cores.
  - **Core Meltdown:**
    - Without cooling, fuel rods overheated and melted in Units 1, 2, and 3.
    - Hydrogen gas buildup led to explosions in reactor buildings of Units 1, 3, and 4.
  - **Radiation Release:**
    - Radioactive isotopes, including Iodine-131 and Cesium-137, were released into the air and ocean.
    - A 20–30 km evacuation zone was enforced to limit public exposure.
- ❖ Despite the efforts of the operators at the Fukushima Daiichi nuclear power plant to maintain control, the reactor cores in Units 1–3 overheated, the nuclear fuel melted, and the three containment vessels were breached. Hydrogen was released from the reactor pressure vessels, leading to explosions inside the reactor buildings in Units 1, 3 and 4 that damaged structures and equipment and injured personnel. Radionuclides were released from the plant to the atmosphere and were deposited on land and on the ocean. There were also direct releases into the sea.

### 6.3 Significance

The Fukushima Daiichi nuclear disaster is regarded as the most severe nuclear accident since the Chernobyl catastrophe of 1986. It was classified as **Level 7** on the International Nuclear and Radiological Event Scale (INES), the highest rating, indicating widespread health and environmental impacts. The event intensified global scrutiny of nuclear safety practices, particularly emphasizing the vulnerability of nuclear facilities to natural disasters and the need for robust disaster-resilient design and preparedness measures.

### 6.4 Radiation Doses Received

- ❖ During the Fukushima Daiichi nuclear accident, a total of 19,594 workers participated in emergency response and cleanup operations.
- ❖ Among them, 167 workers received doses exceeding 100 mSv, and six were exposed to levels greater than 250 mSv.

- ❖ Despite these exposures, no cases of Acute Radiation Syndrome (ARS) or radiation-related fatalities were reported among the workforce.
- ❖ In the general population, approximately 150,000 residents were evacuated from nearby regions.
- ❖ Dose assessments in a sample of 1,700 individuals showed that 98% received less than 5 mSv, and only 10 people recorded doses exceeding 10 mSv.
- ❖ Thyroid dose estimates revealed a mean exposure of 4.2 mSv in children and 3.5 mSv in adults, markedly lower than the approximately 500 mSv thyroid doses observed among evacuees after the Chernobyl disaster.

## **6.5 Health Impact**

- ❖ No radiation-induced deaths have been confirmed following the Fukushima Daiichi nuclear accident. However, the disaster's indirect consequences were substantial: 761 individuals died due to evacuation-related stress, disruption of medical services, and poor living conditions in temporary shelters.
- ❖ The triggering event—the massive tsunami—caused approximately 20,000 fatalities, overshadowing the direct radiological impact.
- ❖ At the radiation levels recorded, a significant increase in thyroid cancer is considered unlikely. While radiation exposure can elevate long-term cancer risk, the extent depends on several factors, including the type and energy of radiation, the absorbed dose, and the specific organs exposed, such as the thyroid, which concentrates radioactive iodine.
- ❖ Children and adolescents remain more vulnerable than adults to such risks.
- ❖ Beyond physical health, the psychosocial impact was profound, with many residents experiencing severe psychological distress driven by prolonged displacement, fear of radiation, and social stigma. Issues in risk communication further challenged public trust during and after the crisis.
- ❖ Independent assessments by the IAEA confirmed that tritium concentrations in the 14<sup>th</sup> batch of ALPS-treated water remained well below Japan's operational safety limits, supporting ongoing reassurance regarding environmental and public health safety.

## 6.6 Key Lessons and Risk Context

- ❖ Radiation doses to both workers and the public were well below ARS thresholds, but evacuation-related harm was substantial.
- ❖ The need to balance radiological protection measures with public health, psychological, and social outcomes is critical.
- ❖ Effective risk communication is essential to help the public understand relative risks and reduce panic.

## 6.7 Management Measures taken:

- ❖ **Radiation Emergency Medical Assistance Team (REMAT®) Deployment to Fukushima – 2011**
  - In the aftermath of the Fukushima Dai-ichi Nuclear Power Station accident on March 11, 2011, the Japanese government activated emergency response mechanisms, including specialized medical teams for radiological events.
- ❖ **Deployment:**
  - The National Institute of Radiological Sciences (NIRS) in Japan immediately dispatched a Radiation Emergency Medical Assistance Team (REMAT®) to the affected region. The REMAT® team was airlifted by a helicopter of the Self-Defense Forces (SDF) to Fukushima.
  - **Deployment and Commendation of NDRF Team (Japan, 2011)**
    - One team (01) of the National Disaster Response Force (NDRF) was deployed to Japan from **27<sup>th</sup> March 2011 to 7<sup>th</sup> April 2011** following the devastating disaster. Despite operating more than two weeks after the calamity, the team successfully extricated seven bodies from the rubble.
    - In addition to rescue and recovery operations, the NDRF team recovered cash amounting to fifty million yen, along with other valuable items, all of which were duly handed over to the concerned authorities.
    - In recognition of the outstanding efforts of the Indian NDRF team, an official commendation was conveyed by the Government of Japan to the Embassy of India on 5 April 2011.

- Residents of the rehabilitation camp at Onagawa Town Hall personally thanked the Indian contingent and shared their experiences with the Contingent Commander. The Mayor of Onagawa highly appreciated the team's apparent dedication and honesty. Additionally, the Mayor of Rifu Cho expressed his gratitude to the Indian team for their assistance and support to the people of Miyagi Prefecture in general and Onagawa in particular.

❖ **Purpose and Actions:**

- Conduct on-site triage and medical evaluation of exposed nuclear workers and emergency responders.
- Provide guidance for decontamination and initial management of potential radiation injuries.
- Set up coordination with local hospitals and emergency response units.
- Monitor radiation doses of workers and evaluate for symptoms of Acute Radiation Syndrome (ARS).

❖ **Significance:**

- The early deployment of REMAT<sup>®</sup> by air transport ensured timely medical support, minimized delays, and helped coordinate protective measures for both patients and healthcare providers.
- This rapid response model is now viewed as a best practice for future radiological and nuclear emergencies.

**6.8 Status of Local Emergency Headquarters – Ōkuma-machi (12–15 March 2011)**

During the critical early days of the Fukushima Dai-ichi nuclear accident, the Local Headquarters for Nuclear Emergency Response was established in Ōkuma-machi, the town nearest the power station. The situation on the ground posed severe challenges to effective emergency coordination.

Key Challenges:

❖ **Communication Breakdown**

- Mobile networks, internet, fax, and landline telephone services were non-functional.

- Only two satellite phones were operational, severely limiting external communication.

❖ **Infrastructure Collapse**

- Complete power outage: No electricity supplies to run equipment or lighting.
- No running water, impacting hygiene and cooling systems.
- Fuel and battery shortages constrained generator use.

❖ **Operational Difficulties**

- A Joint Meeting for Nuclear Emergency Response was conducted on March 12, but coordination was hampered by lack of communication and logistics.
- Severe weather and tsunami damage further isolated the headquarters.

❖ **Implications**

- The response had to rely heavily on manual reporting, delayed updates, and limited situational awareness.
- Evacuation orders, risk assessments, and radiation monitoring were delayed or improvised.
- The incident highlighted the need for hardened, redundant communication systems and self-sufficient emergency command centers in nuclear preparedness planning.

## 6.9 Regulatory Change for Emergency Workers – Fukushima Dai-ichi (2011)

❖ **Background:**

- In response to the severe nuclear crisis following the Great East Japan Earthquake and tsunami on March 11, 2011, emergency response teams had to enter high-radiation zones within and around the Fukushima Dai-ichi Nuclear Power Station.

❖ **Regulatory Measure:**

- On March 14, 2011, the Japanese Ministry of Health, Labour and Welfare (MHLW) revised the occupational radiation dose limit for emergency workers from: 100 mSv → 250 mSv

- ❖ This regulation was made specifically for this accident, considering the urgent need for intervention under dangerous conditions.

❖ **Rationale:**

The International Commission on Radiological Protection (ICRP) recommends higher dose limits in life-saving or disaster-mitigation scenarios, provided that informed consent is obtained.

The temporary increase allowed workers to perform critical safety operations including reactor cooling, radiation containment, and environmental monitoring.

❖ **Application and Oversight:**

Applied only to registered emergency workers involved in managing the Fukushima accident.

Strict health monitoring and radiation dose tracking were implemented for those exposed beyond the normal occupational limits.

❖ **Post-Event Review:**

Later assessments indicated that 167 workers received >100 mSv, and 6 workers >250 mSv.

No cases of Acute Radiation Syndrome (ARS) or radiation-related deaths were reported among workers, though long-term health surveillance is ongoing.

## 7. History of Accident: Case Study: Mayapuri Radiological Accident, New Delhi, India (2010)

### ❖ Mayapuri Radiological Accident, New Delhi, India (2010)

#### Cause:

- **Disposal failure:** Delhi University dismantled and auctioned a Gamma Cell 220 irradiator (with decayed Co-60) as scrap without AERB authorization.
- **Orphan source creation:** Highly radioactive Cobalt-60 pencils reached scrap market unknowingly.
- **Unsafe handling:** Scrap workers manually cut/opened the irradiator, leading to direct exposure.
- **Regulatory lapses:** Poor inventory tracking, lack of training, and non-compliance with disposal rules.

#### Impact:

- 8 cases of Acute Radiation Syndrome (ARS); 1 fatality in a worker who handled source pencils (~3.1 Gy).
- Clinical effects: skin burns, pancytopenia, infections, GI symptoms, multi-organ failure.
- Environmental contamination: soil and scrap contaminated; 400 kg soil + 100 kg scrap removed.
- Large-scale response: area cordoned, multi-agency involvement (AERB, BARC, NDMA).
- Social impact: fear in local community, disruption of scrap-market operations.

#### Lessons Learnt:

- Strict disposal protocols needed for all radioactive sources, especially in academic institutions.
- Mandatory inventory management & traceability (led to creation of eLORA system by AERB).
- Training & awareness for institutions handling radiation equipment.
- Preparedness & rapid response essential—coordination between regulators and emergency agencies.
- Prevent orphan sources: ensure secure storage, licensing, and monitoring of all radiation sources.

Box 4.6- Summary of Mayapuri Radiological Accident, New Delhi, India (2010)



Fig.no. 4.6 – Mayapuri Radiological Accident, New Delhi, India (2010)

### 7.1 Introduction:

- ❖ In April 2010, a significant radiological accident occurred in Mayapuri, New Delhi, leading to multiple cases of radiation exposure and one fatality. The event served as a wake-up call for regulatory authorities, institutions, and the public on the safe management and disposal of radioactive sources.
- ❖ Mayapuri, located in West Delhi, was historically a hub for small-scale heavy metal industries. Following government restrictions, many heavy metal operations moved out. The area evolved into a mix of residential flats, a large metal scrap market, small factories, and automobile service stations—making it a high-risk environment for unregulated handling of hazardous materials.

### 7.2 About Gamma Cell Involved

- ❖ The accident involved a Category-I Self-contained Dry Source Storage Irradiator (Model Gamma Cell 220) manufactured by Atomic Energy Canada Ltd. (AECL) and purchased by Delhi University in 1969.

- **Original activity:** 147.186 TBq (3,978 Ci) of Cobalt-60 in 16 pencils (each with 7 slugs).
- **Shielding:** ~3 tonnes of lead.
- **Status in April, 2010:** the total activity had decayed to ~688.2 GBq (18.6 Ci).

### 7.3 Timeline of Events

- **March 2010** – Scrap dealer dismantles the irradiator; source pencils handled without protection.
- **Early April 2010** – Scrap dealer and workers develop symptoms: skin hyperpigmentation, hair loss, nausea, and fatigue.
- **April 4, 2010** – First patient admitted to hospital; suspected radiation injury.
- **April 7–9, 2010** – AERB, NDMA, BARC, and Narora teams identify and recover radioactive material from multiple shops.
- **April 13–17, 2010** – Additional recovery operations retrieve remaining source components.
- **April 22, 2010:** Reported to IAEA with provisional Level 3 (Incident).
- **May–June 2010** – Decontamination operations remove ~400 kg contaminated soil and 100 kg contaminated scrap.
- **July 2010** – July 17, 2010: Final rating revised to Level 4 (Accident) on the INES scale

Box 4.7- Timeline of Events

### 7.4 Phases of Accident Handling

#### ❖ Initial Phase – Emergency First Response

- On April 7, 2010, the Atomic Energy Regulatory Board (AERB) received a report from a hospital in Delhi regarding a 32-year-old scrap shop owner exhibiting symptoms consistent with radiation exposure.
- In response, AERB officers promptly conducted on-site radiation surveys and detected elevated radiation levels, reaching up to 45 mSv/h in certain shops.

- Concurrently, medical guidance was provided to hospitals to support the management and treatment of the affected individual.

❖ **Accident Control Phase – Radiation Protection**

- Between April 8 and 17, 2010, the recovery of radioactive sources was carried out in three stages to ensure radiation protection and accident containment.
- Phase I (April 8–9): Four source pencils, three gunny bags, and a drum of radioactive scrap were recovered.
- Phase II (April 13–14): One source pencil, a cylindrical source cage, and an additional drum of contaminated scrap were retrieved.
- Phase III (April 16–17): A single Cobalt-60 slug, found in a wallet, was recovered.
- All recovered sources were safely transported to an authorized disposal facility using shielded flasks and remote handling techniques, minimizing exposure risks to personnel and the public.

❖ **Post-Emergency Phase – Clean-up (May–June 2010)**

- During the post-emergency phase, extensive clean-up operations were carried out. Approximately 400 kg of contaminated soil and 100 kg of radioactive scrap were removed from the affected areas.
- Excavation and decontamination of the sites were performed, followed by concreting of contaminated surfaces to prevent residual radiation hazards.
- Subsequent radiation monitoring confirmed that post-cleanup radiation levels had returned to normal background levels, ensuring the area was safe for reoccupation.

## **7.5 Investigation of Source Origin**

- ❖ At the outset, the origin of the radioactive source was unclear. Detailed examination in a hot cell—a heavily shielded facility designed for the safe handling and inspection of high-activity materials—revealed that the recovered components belonged to a Gamma Cell containing 48 source slots.
- ❖ Further confirmation came when one of the affected individuals recognized the device from photographs as equipment that had been dismantled in Mayapuri.

- ❖ The accountability trail ultimately led investigators to the Delhi University Chemistry Department, where disposal records matched the auctioned equipment.
- ❖ This was corroborated by documentation from the original supplier, AECL, and regulatory records maintained by the AERB, conclusively establishing the provenance of the source.

## **7.6 Exposure and Medical Impact**

- ❖ Eight individuals, including a scrap dealer, workers, and others in the vicinity, were diagnosed with Acute Radiation Syndrome (ARS) following exposure.
- ❖ The most severe case involved a 26-year-old laborer who had directly handled Cobalt-60 pencils; despite 17 days of intensive care, he succumbed to septic shock, bilateral pneumonia, and multi-organ failure associated with hematopoietic and gastrointestinal syndromes.
- ❖ The estimated radiation dose for this individual was approximately 3.1 Gy, as assessed by BARC.
- ❖ Common symptoms observed among the victims included pancytopenia, gum bleeding, skin lesions, pneumonia, and progressive multi-organ dysfunction.
- ❖ Ultimately, this exposure resulted in one fatality due to complications from septic shock and multi-organ failure.

## **7.7 Autopsy Findings of Fatal Case**

- ❖ The autopsy of the fatal case revealed significant external and internal findings.
- ❖ Externally, the body exhibited hyperpigmentation, black patches, and jaundice affecting the sclera and nails.
- ❖ Internally, there were pleural and peritoneal effusions, congested lungs with fibrinous exudates, gastric ulcerations, and congested kidneys showing patchy tubular atrophy.
- ❖ Histopathological examination confirmed bone marrow suppression, severe systemic infection, and gastrointestinal bleeding, consistent with the effects of high-dose radiation exposure.

## **7.8 Regulatory and Technical Response**

- ❖ In response to the incident, immediate regulatory and technical measures were implemented.

- ❖ **Emergency Measures:** The affected area was cordoned off, and detailed radiation mapping was conducted.
- ❖ The radioactive source was safely recovered using shielded flasks and remote handling techniques.
- ❖ **Decontamination** efforts included excavation and disposal of contaminated soil and scrap, with affected surfaces subsequently concretized to prevent further spread.
- ❖ Following the incident, a series of **post-incident actions** were undertaken at the national level. These included a comprehensive verification of radioactive source inventories across the country, as well as awareness campaigns and training programs focused on the safe disposal of radioactive materials.
- ❖ To strengthen regulatory oversight, the Atomic Energy Regulatory Board (AERB) introduced the e-Licensing of Radiation Applications (eLORA) system, an online platform for the registration, licensing, and tracking of radiation sources in India. (<https://elora.aerb.gov.in/ELORA/populateLoginAction.htm>)
- ❖ The system is designed to maintain a national inventory of radioactive sources, ensure safe handling, and prevent the occurrence of orphan sources.
- ❖ Key features of eLORA include online licensing, automated compliance checks, inspection management, and real-time source tracking, thereby enhancing overall safety and regulatory compliance.

## 7.9 Lessons Learned

- **Critical Gap in Disposal Oversight:** University failed to comply with safe disposal regulations, enabling hazardous material to enter scrap trade.
- **Need for Continuous Regulatory Vigilance:** Periodic audits and strict inventory tracking are essential.
- **Importance of Awareness:** Users of radiation sources (especially in academic settings) must be trained in regulatory compliance.
- **Emergency Preparedness:** Rapid multi-agency coordination (AERB, NDMA, BARC) was crucial to containing the hazard.

- **Public Safety:** Disposal protocols must ensure radioactive materials cannot be accessed by untrained personnel.

### Take Home Message:

- ❖ **Types and causes of radiation accidents:** Include nuclear power plant failures, medical or industrial mishandling of radioactive sources, radiological dispersal incidents, and transport accidents; typically caused by human error, equipment failure, natural disasters, or sabotage.
- ❖ **Lessons from past accidents:** Robust safety design, emergency preparedness, proper handling of radioactive sources, and importance of regulatory oversight and trained personnel.

### References (Adapted from)

- Hall, E. J., & Giaccia, A. J. (2019). *Radiobiology for the Radiologist* (8th ed.). Wolters Kluwer.
- UNSCEAR. (2000). *Sources and Effects of Ionizing Radiation*. United Nations Scientific Committee on the Effects of Atomic Radiation.
- ICRP. (2007). *The 2007 Recommendations of the International Commission on Radiological Protection*. ICRP Publication 103.
- Bromet, E. J. (2012). Mental health consequences of the Chernobyl disaster. *Journal of Radiological Protection*, 32(1), N71-N75.
- IAEA. (2010). *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*.
- TEPCO. (2011). *Fukushima Nuclear Accident Analysis Report*.
- IAEA (2018) *Emergency Preparedness and Response*.
- National Council on Radiation Protection and Measurements (NCRP). (2020). *Population Monitoring and Medical Assessment After a Radiological Emergency*.
- U.S. Nuclear Regulatory Commission. (2016). *Radiation Protection and the NRC*

- [https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1798\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1798_web.pdf)
- <https://www.britannica.com/event/Fukushima-accident>
- IAEA (2006). Chernobyl's Legacy: Health, Environmental and Socio-economic Impacts (<https://www.iaea.org/sites/default/files/chernobyl.pdf>)
- WHO (2006). Health Effects of the Chernobyl Accident and Special Health Care Programmes
- UNSCEAR (2008). Sources and Effects of Ionizing Radiation: Volume II
- BARC & AERB Emergency Response Guidelines
- IAEA. The Chernobyl Accident: Updating of INSAG-1, Safety Series No. 75-INSAG-7, 1992.
- WHO (2006) Health Effects of the Chernobyl Accident and Special Health Care Programmes, 2006.
- UNSCEAR. 2008 Report Vol II: Effects of Radiation Exposure.
- Andrews GA, et al. Lymphocyte Depletion Kinetics for Dose Estimation, Health Physics, 1981.
- IAEA. Manual for First Responders to a Radiological Emergency, EPR-First Responders, 2006.
- IAEA (2015). The Fukushima Daiichi Accident
- WHO (2013). Health Risk Assessment: Fukushima Nuclear Accident
- UNSCEAR (2020). Scientific Findings on Radiation Exposure from the Accident
- IAEA (2015). The Fukushima Daiichi Accident – Report by the Director General
- UNSCEAR (2020). Scientific evaluation of health and environmental effects of the Fukushima accident
- WHO (2013). Health Risk Assessment from the Nuclear Accident after the 2011 Great East Japan Earthquake and Tsunami
- NIRS Japan (2011). Report on Medical Response to Fukushima Accident ([https://www.nirs.org/wp-content/uploads/fukushima/naic\\_report.pdf](https://www.nirs.org/wp-content/uploads/fukushima/naic_report.pdf))
- IAEA (2015). The Fukushima Daiichi Accident – Technical Volume 2: Emergency Preparedness and Response (<https://www-pub.iaea.org/MTCD/Publications/PDF/AdditionalVolumes/P1710/Pub1710-TV2-Web.pdf>)

- Japanese Government (2011). Report of Japanese Government to the IAEA Ministerial conference on Nuclear Safety
- WHO (2013). Health Risk Assessment from the Nuclear Accident after the 2011 Great East Japan Earthquake and Tsunami
- Ministry of Health, Labour and Welfare, Japan (2011). Notification on Temporary Revision of Emergency Dose Limits
- ICRP Publication 109 (2009). Application of the Commission's Recommendations for the Protection of People in Emergency Exposure Situations
- IAEA. (2009). Lessons Learned from Accidental Exposures in Radiotherapy
- WHO. (2017). Medical Management of Radiation Emergencies
- IAEA. (2018). Safety Report Series No. 104: Accidental Overexposure of Radiotherapy Patients
- UNSCEAR (2020). Sources, Effects and Risks of Ionizing Radiation
- <https://www.who.int/news-room/fact-sheets/detail/health-effects-of-the-chernobyl-accident>
- <https://www.iaea.org/topics/Chernobyl>
- [https://www.unscear.org/docs/reports/2008/11-80076\\_Report\\_2008\\_Annex\\_D.pdf](https://www.unscear.org/docs/reports/2008/11-80076_Report_2008_Annex_D.pdf)
- <https://www.oecd-nea.org/news/press-kits/chernobyl/>
- NDRF

(<https://www.ndrf.gov.in/en/operations/japan-tsunami-mar-2011#:~:text=01%20Team%20of%20NDRF%20was,general%20and%20Onagawa%20in%20particular.>)

- Image:
  1. Fig.no. 4.1 (IAEA)
  2. Fig.no. 4.2 [History Extra (<https://www.historyextra.com/period/20th-century/chernobyl-disaster-1986-reactor-four-what-happened-why-when-facts/?>)]

3. Fig.no. 4.3 (UNSCEAR - [www.unscear.org/docs/reports/2008/11-80076\\_Report\\_2008\\_Annex\\_D.pdf](http://www.unscear.org/docs/reports/2008/11-80076_Report_2008_Annex_D.pdf))
4. Fig.no.4.4 (Getty images:  
<https://assets2.cbsnewsstatic.com/hub/i/r/2019/05/31/678c41a6-442e-4d37-83de-28f052d41725/thumbnail/620x414/3817ec68b0a42df59655a1085985a398/evac.jpg>)
5. Fig.no.4.5 (The Chemical Engineer: The Fukushima Nuclear Disaster: Then and Now - <https://www.thechemicalengineer.com/features/the-fukushima-nuclear-disaster-then-and-now>)
6. Fig.no.4.6 (<https://www.ntanet.net/wp-content/uploads/2023/08/The-Accident-Archives-New-Delhi-India-2010.png>)

### **Suggested Reading**

- IAEA (2006). Chernobyl's Legacy: Health, Environmental and Socio-economic Impacts (<https://www.iaea.org/sites/default/files/chernobyl.pdf>)
- WHO (2006) Health Effects of the Chernobyl Accident and Special Health Care Programmes, 2006.

## Chapter 5

### Disaster Management: An overview (Radio-nuclear emergencies)

#### 1. Introduction

##### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand the role of NDMA and NDRF in the management of radio-nuclear emergencies.
- Understand components of India's national preparedness and response system, guided by standards and frameworks from the International Atomic Energy Agency (IAEA), the World Health Organization (WHO), the Atomic Energy Regulatory Board (AERB), and the Bhabha Atomic Research Centre (BARC).

The increasing frequency and intensity of disasters—both natural and human-induced—have necessitated a structured and institutionalized approach to disaster risk management in India. The National Disaster Management Authority (NDMA), constituted by virtue of Disaster Management Act, 2005, serves as the apex policy-making and coordinating body for disaster management in the country. An important mandate is the formulation and implementation of the National Disaster Management Plan (NDMP). The NDMA was first developed in the year 2016 and revised and updated in the year 2019. The current version of NDMP i.e. NDMP 2019 is a comprehensive document which serves varied purposes. This includes a broader guidance on India's Disaster Management framework to internal and external stakeholders. It is also a strategic and operational Disaster Management Plan of the nation, that paves the path for disaster risk reduction, mitigation, preparedness, response, and recovery at all levels of governance.

The NDMA plays an important role in shaping, operationalizing, and steering the National Disaster Management Plan and the broader disaster risk governance framework in India.

## **2. NDMA: Vision and Legal Mandate**

- ❖ The NDMA is headed by the Prime Minister of India as the Chairperson, reflecting the national importance accorded to disaster risk management. Its establishment under the Disaster Management Act of 2005 marked a paradigm shift from a relief-centric approach to a holistic, integrated, and proactive risk management framework.
- ❖ The Authority is legally mandated to:
  - Lay down policies, plans, and guidelines for disaster management;
  - Ensure a timely and effective response to disasters;
  - Coordinate disaster mitigation, prevention, preparedness, and capacity-building activities across ministries, departments, and states.

## **3. The National Disaster Management Plan (NDMP)**

- ❖ The National Disaster Management Plan (NDMP), 2016 is the first-ever national plan prepared under the Disaster Management Act, 2005. It was updated in the year 2019 to reflect emerging hazards, global frameworks like the Sendai Framework for Disaster Risk Reduction, Paris Agreement on Climate Change and Sustainable Development Goals.
- ❖ The NDMP is both a strategic and operational document that guides the functioning of the entire disaster management ecosystem in India. It reflects a multi-hazard, multi-sectoral, and multi-stakeholder framework and serves as guidance for Ministry/departmental disaster management strategies, State Disaster Management Plans (SDMPs) and District Disaster Management Plans (DDMPs) etc.

## **4. NDMA's Responsibilities Related to the NDMP**

### **4.1 Guiding Ministry and State-Level Plans**

- ❖ In addition to the NDMP, ministries and states are required to prepare their own disaster management plans. NDMA:

- Issues model templates and planning guidelines;
- Reviews ministry-level plans for compliance and coherence with the NDMP;
- Facilitates periodic reviews and updates to reflect best practices and emerging risks.

#### **4.2 Coordination and Capacity Building**

NDMA plays a coordinating and enabling role in the implementation of the NDMP. This includes:

#### **4.3 Inter-Ministerial and Inter-State Coordination**

NDMP also acts as an enabling mechanism for the Whole of Government and Whole of Society approach and realization of the Hon'ble Prime Minister's 10-point agenda on Disaster Risk Reduction. Where, the Ministries and states & UTs are aligned with the NDMP through regular consultations, joint exercises, and Committee on Disaster Risk Reduction (CoDRR) workshops. This coordination ensures synergy between the national and sub-national landscape on disaster risk management.

#### **4.4 Capacity Development**

- ❖ NDMA is responsible for building the capacities of institutions and communities for disaster preparedness. This is implemented through:
  - Synergy with the National Institute of Disaster Management (NIDM);
  - Development of training modules and simulation exercises;
  - Supporting research, documentation, and knowledge sharing.

NDMA also lays down broad policies and guidelines for NIDM, ensuring that its training and research broadly supports the goals of the NDMP.

#### **4.5 Laying Down Technical and Operational Guidelines**

- ❖ The NDMP is operationalized through guidelines for Hazard specific, Facility and Cross-cutting issues, besides Research and Publication, Outreach and public awareness through

Consultations, Programs and Projects broadly classified in following categories Mitigation, Policy & plan, Capacity Building and Training, Recovery and Reconstruction and Public Relation and Awareness Generation.

❖ NDMA has developed detailed guidelines for hazards such as:

- Earthquakes
- Urban flooding
- Cyclones
- Landslides
- Industrial and chemical disasters
- Heat waves
- Biological and public health emergencies
- Nuclear and radiological emergencies

These guidelines are available online at -<https://ndma.gov.in/Governance/Guidelines>

❖ These guidelines specify:

- Vulnerability assessments and risk zoning;
- Role of stakeholders;
- Emergency medical and evacuation;
- Early warning and dissemination mechanisms.

#### **4.6 Financing and Resource Mobilization**

❖ NDMA plays a key advisory role in resource mobilization and financial planning for disaster risk management:

- It recommends provisions of funds for disaster mitigation and capacity building;
- It guides ministries in integrating DRR into centrally sponsored schemes such as the Smart Cities Mission, Jal Jeevan Mission, or Pradhan Mantri Awas Yojana.

#### 4.7 Innovations and Digital Tools

- ❖ NDMA is increasingly promoting the application of technology and innovation into the NDMP's implementation:
  - Use of GIS-based hazard mapping, early warning systems, and mobile applications;
  - Promoting real-time dashboards and data management platforms;
  - Promotes application of Artificial Intelligence, Machine Learning based intelligent systems for disaster risk management.

#### 5. Role of NDRF in the Management of Radio-Nuclear Emergencies

- ❖ The National Disaster Response Force (NDRF) plays a critical role in India's national framework for disaster preparedness and response.
- ❖ Among the various hazards it responds to, radiological and nuclear emergencies require specialized capabilities, coordination with atomic energy and health agencies, and strict adherence to radiation safety protocols.
- ❖ Its functions are guided by the **Disaster Management Act, 2005**, and coordinated with agencies like NDMA, AERB, BARC, and local authorities.

##### 5.1 Mandate and Preparedness

- ❖ The NDRF, under the Ministry of Home Affairs (MHA), is mandated to respond to all types of disasters, including chemical, biological, radiological, and nuclear (CBRN) incidents. Following the NDMA Guidelines on Nuclear and Radiological Emergencies (2009), NDRF battalions are equipped and trained to manage radiation emergencies arising from:
  - Accidents at nuclear facilities (e.g., power reactors, fuel reprocessing plants)
  - Radiological accidents during transportation or misuse of radioactive sources
  - Radiological Dispersal Devices (RDDs) or "dirty bombs"
  - Malevolent acts involving nuclear materials

## 5.2 Specialized Training and Capability

- ❖ To deal with radiological emergencies effectively, NDRF personnel undergo regular training programs and mock drills in collaboration with:
  - BARC (Bhabha Atomic Research Centre)
  - AERB (Atomic Energy Regulatory Board)
  - DAE (Department of Atomic Energy)
  - IAEA-recognized training modules
- ❖ Each battalion includes a CBRN response team trained in:
  - Detection and identification of radioactive materials using handheld radiation survey meters and dosimeters
  - Decontamination procedures (personnel and surface)
  - Use of Personal Protective Equipment (PPE)
  - Establishment of exclusion, contamination control, and decontamination zones
  - Casualty triage and coordination with medical services for internal dosimetry and treatment

## 5.3 Response Roles During a Radio-Nuclear Emergency

### ❖ Rapid Deployment and Situation Assessment

- Immediate mobilization to the site
- Radiological reconnaissance to map contamination using radiation detection equipment
- Establishment of a command-and-control structure with the local administration and DAE authorities

### ❖ Public Protection and Communication

- Assisting in evacuation and sheltering based on plume modelling and radiation spread
- Implementing cordon and perimeter control to restrict access to contaminated zones
- Public awareness and communication to prevent panic and misinformation

### ❖ Technical Support and Coordination

- Supporting civil authorities, district administration, and atomic energy establishments
- Assisting in packaging and safe transport of radioactive materials if required

- Participating in joint response with local emergency services, CRPF, civil defence, and health authorities

❖ **Post-Incident Recovery**

- Helping in environmental monitoring and clean-up operations
- Assisting in long-term monitoring of affected populations (in coordination with health agencies)
- Ensuring proper documentation and follow-up decontamination efforts

**5.4. Equipment and Resources**

- ❖ Each NDRF battalion responding to radiological emergencies is equipped with:
  - Radiation detection devices (e.g., GM counters, scintillation detectors, area survey meters)
  - Personal dosimeters and alarms
  - Decontamination kits and mobile showers
  - Portable shielding and containment devices
  - CBRN suits, respirators, gloves, boots, and masks

**5.5. Coordination with National and International Agencies**

- ❖ NDRF operates within a broader framework involving:
  - NDMA for policy and strategic coordination
  - DAE and AERB for technical support
  - BARC for scientific input and training
  - IAEA and WHO for international guidelines and radiation emergency protocols

**11. National Framework for Preparedness and Response to Radio- nuclear Emergencies**

**11.1 Purpose:**

The main purpose of Nuclear and Radiological Emergency (NRE) management is to protect public health from radiation exposure and minimize the impact on property and the environment. The

process of preparing for and responding to such emergencies involves multiple jurisdictions and organizations and spans various levels of government responsibilities.

### **11.2 Objective:**

National framework outlines coordination to respond to NRE and fulfill following objectives:

- To outline the roles and responsibilities of the various government agencies, ministries and departments in the preparedness and response.
- To strengthen the preparedness and response capabilities of the various systems, agencies and organizations involved.
- To serve as an instrument to mitigate, prepare, respond and recover.
- To protect the public, emergency workers, environment and society as a whole in all phases of nuclear and radiological emergencies.

### **11.3 Mandate:**

- ❖ The Crisis Management Plan of the Government of India, which was first issued by Cabinet Secretariat in 1987 and latest in 2019 (CMP-2019), has designated the 'Department of Atomic Energy' along with MHA as the Central Nodal Ministry/Department responsible for handling any nuclear or radiological emergencies (NRE) in public domain in the country.
- ❖ The National Disaster Management Plan-2019 of NDMA also identifies DAE as the lead department to provide technical support and expert guidance to deal with any NRE in the country.
- ❖ To fulfill this mandate and also in compliance with the recommendations of the Cabinet Secretariat, Government of India, a "Crisis Management Group" (CMG) was constituted in the DAE in 1987.

### **11.4 Organizational structure:**

- ❖ Crisis Management Group, DAE (CMG-DAE) is an apex committee of the department, comprising senior officials drawn from different DAE units.

- ❖ Head, Nuclear Controls and Planning Wing (NCPW), DAE is the ex-officio Chairman of the CMG-DAE and is supported by Member-Secretary of CMG-DAE. Director/Associate Director, Health Safety & Environment Group, BARC is the ex-officio Radiation Emergency Response Director (RERD), who is the lead coordinator for providing radiation measurement, monitoring and guidance on protection services.
- ❖ CMG facilitates necessary co-ordination between DAE, the local, district authorities (DDMA/SDMA) in the affected area, National Disaster Management Authority (NDMA) and other Central agencies for arranging necessary technical support for effectively handling the emergency.
- ❖ DAE-DMC provides necessary support to the Disaster Management Cell of the affected DAE unit when a requirement arises for coordinating response / mitigation actions with the state/central agencies.

#### **11.5 Emergency Management:**

- ❖ Availability of the Emergency Control Rooms (ECRs) located in Mumbai at two different places in Mumbai, which are backing up one another, is ensured throughout the year. These control rooms, manned on round-the-clock basis and equipped with diverse means of communication; remain in contact with the various nuclear facilities in the country, the Ministry of Home Affairs (MHA) as well as with the International Atomic Energy Agency (IAEA) in Vienna. The Emergency Control Rooms of DAE are the National Contact Point for nuclear and radiological emergency. To maintain a high state of readiness of emergency plans, major nuclear facilities (nuclear power stations and heavy water plants) conduct various emergency exercises.
- ❖ CMG-DAE also acts as a National warning point under the International Atomic Energy Agency's conventions of 'Early Notification' and 'Assistance' in case of nuclear accident or radiological emergency, to which India is a signatory.
- ❖ The CMG DAE also relies upon the network of Radiation Emergency Response Centers (DAE-RERCs) at various locations in the country for technical support and assistance.
- ❖ A network of 25 Radiation Emergency Response Centers (RERCs) has presently been established at 25 locations across the country to deal with any radiation emergency in the public domain. The responsibilities of the RERCs are to provide field response comprising

radiation detection, monitoring, radiological assessment, maintain adequate inventory of monitoring instruments and protective gear, provide the technical inputs to CMG-DAE for decision making and provide technical advice to the first responders and the local authorities.

- ❖ CMG-DAE has been entrusted with the role of all the facets of preparedness, planning, capacity building and response to any NRE situation in the country. The functions of CMG are supported by various Resource Groups which provide assistance and support in the areas of radiation measurement and protection, medical assistance to radiation affected personnel, radioactive waste management and communication support.

#### **11.6 Nuclear Emergency from a Nuclear Facility:**

- ❖ Off-site emergency response framework exists with all NPPs, in which the Site Emergency Director (SED) coordinates with the District Administration and recommends protective actions during the early phase of the Off-site emergency.
- ❖ In the intermediate phase of the Off-site emergency, National Radiation Emergency Response Director (RERD), DAE coordinates with the District Administration and provides recommendations on protective actions for effective response in the public domain. RERD through its countrywide network of 25 DAE-Radiation Emergency Response Centers (DAE-RERCs) can mobilize radiation protection experts for providing necessary technical expertise to the District Administration and to designated response forces (NDRF/SDRF) till the termination of emergency situations.

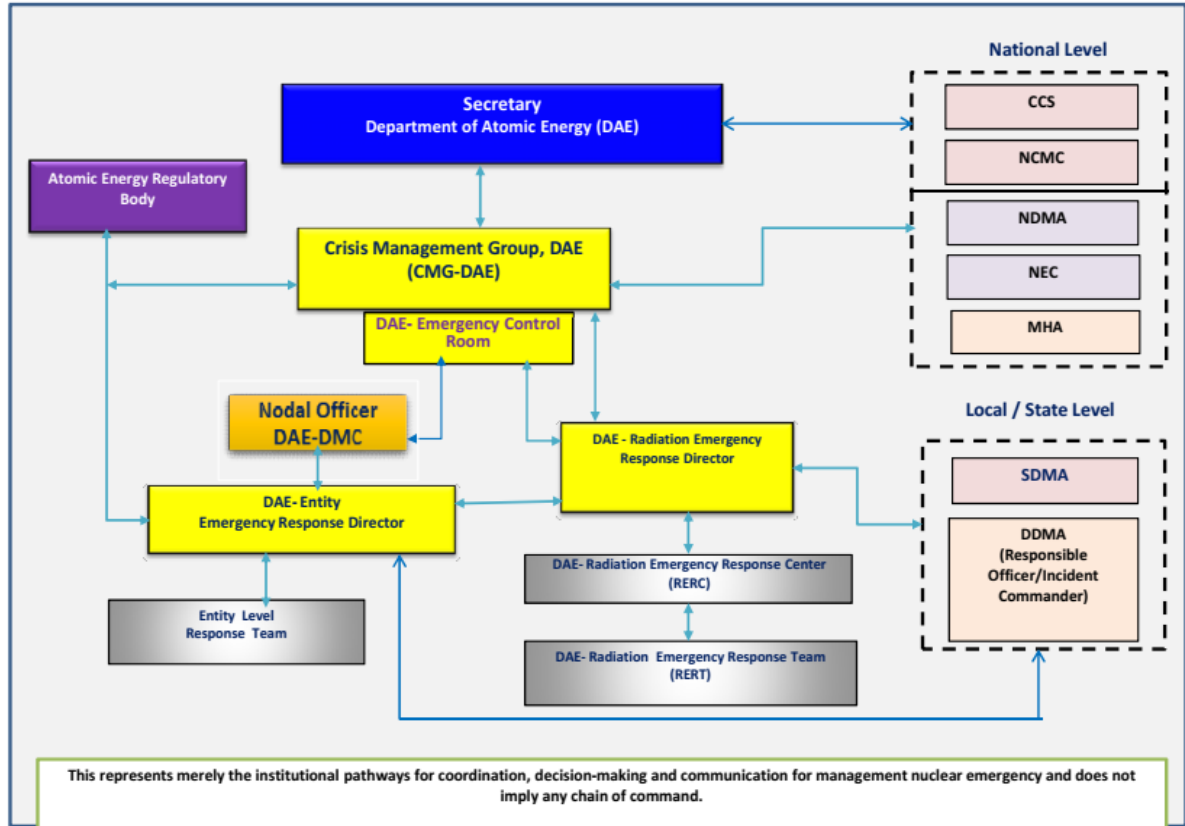


Fig.no. 5.1 - Crisis management during a nuclear or radiation emergency under DAE

### 11.7 Radiological Emergency in Public Domain:

- ❖ Crisis Management Group of DAE is the nodal agency for receiving notification from an individual/local authority/district authority/customs/airports/border posts/management of metal recycling plant /scrap trader etc., regarding any radiological emergency or any event involving presence of radiation sources or radioactive contaminated material in public domain. The information received from any individual in public domain is to be sent to Office of Inspector General (IG), DAE, for communicating with the local police station/local authority about its authenticity and necessary action thereafter.
- ❖ Based on the assessment of the information from various agencies, the Member-Secretary, CMG-DAE / Alternate Member-Secretary, CMG-DAE should inform RERD, DAE / Alternate RERD, DAE, who in turn will activate the Nodal DAE-RERC for necessary response action or coordinate with other DAE-RERCs for necessary response to the radiological event.

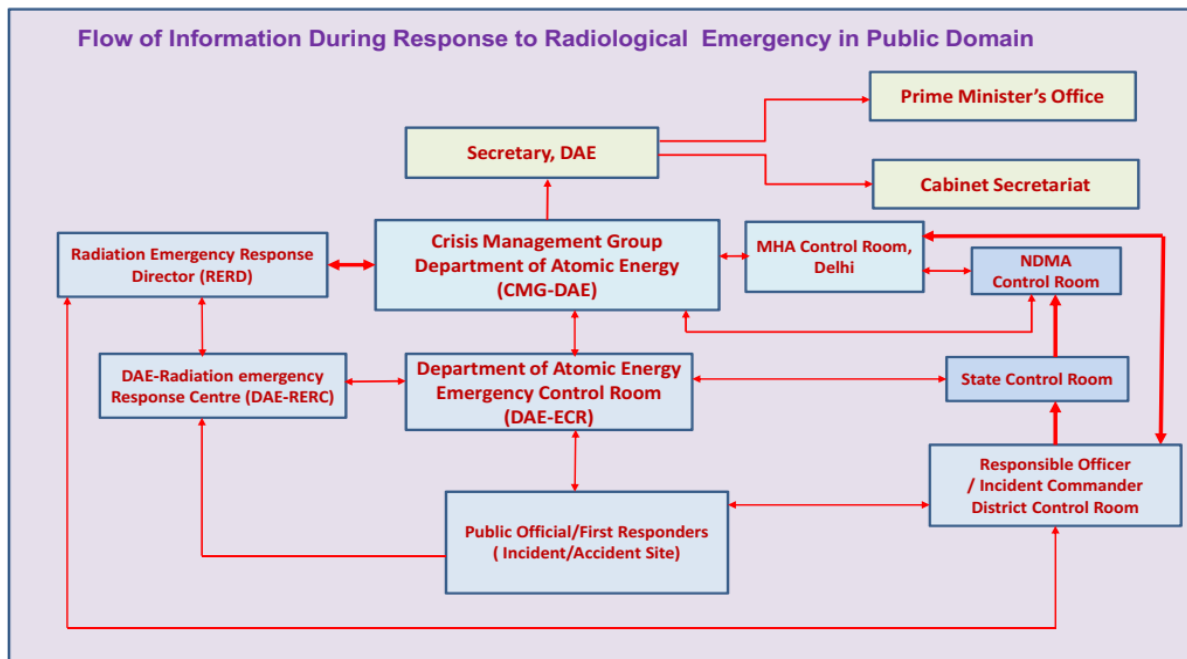


Fig.no. 5.2 – Flow of information during response to radiological emergency in public domain

- ❖ The Department of Atomic Energy (DAE) maintains a 24x7 manned Emergency Control Room at its headquarters in Anushakti Bhavan, Colaba, Mumbai, with a standby control room at NPCIL Headquarters, Vikram Bhavan, Anushaktinagar, Mumbai. This facility serves as the National Contact Point for any radiological or nuclear emergency in the public domain and functions as the National Warning Point for the IAEA’s emergency communications. To ensure rapid and effective response across the country, the DAE has also established 25 well-equipped Radiation Emergency Response Centers (RERCs) strategically located nationwide. (Refer Table 5.1)

	Phone	Fax	E- mail
Anushakti Bhavan, C.S.M Marg, Mumbai PIN 400001  (24X7 operational)	022-22023978  022-22021714  022-25505300  022-22862595	022-22830441	daeecr@dae.gov.in

	<b>022-22862582</b> <b>09969201364</b>		
	<b>Alternate DAE Emergency</b>	<b>Control Room</b>	
<b>VS Bhavan</b>  <b>Anushatki Nagar, Mumbai</b>  <b>PIN 400094</b>  <b>(24X7 operational)</b>	<b>022-25991070</b>  <b>022-25991071</b>  <b>09969201365</b>	<b>022-2599 1080</b>  <b>022-2559 3080</b>  <b>022-2551 5283</b>	<b>vsbecr@npcil.co.in</b>

Table 5.1 - DAE Emergency Control Rooms

## 11.8 Medical Management

- ❖ It is imperative to have defined organizational plan for medical response in NRE.
- ❖ Medical responders trained in medical management of NRE have a critical role in providing immediate pre- hospital and hospital care, managing contamination, mitigating long-term health consequences, transport to definitive care facility, Co-ordination with Technical experts and local Health Officials.
- Initial Assessment and Triage
- Treatment of Life-threatening Injuries, Resuscitation and Stabilization
- First-Aid to the casualties
- Treatment of Radiation Injuries
- Decontamination and Decorporation.
- Monitoring and long-term Follow-up
- Mental health services for patients and their families

## Take Home Message:

- ❖ The NDMA while formulates the National Disaster Management Plan also presents an enabling mechanism. This involves policy guidance, institutional coordination, capacity building, Programme formulation and implementation, facilitation, and knowledge dissemination. Thus, National Disaster Management Plan paves the path towards a disaster-resilient society—that responds effectively to emergencies while anticipating and mitigating risks.
- ❖ The NDRF serves as India’s frontline force for managing the immediate consequences of radio-nuclear emergencies. With its dedicated CBRN units, advanced equipment, and coordination with atomic and health authorities, NDRF plays a pivotal role in safeguarding public health and restoring normalcy after a radiological event. Continuous training, inter-agency drills, and adherence to international safety standards remain crucial to enhancing the effectiveness of NDRF's response capabilities.
- ❖ India’s national preparedness system: Guided by IAEA, WHO, AERB, and BARC standards; includes regulatory oversight, emergency planning, early warning systems, trained response teams, public communication, medical management, and coordination among central and state agencies to ensure effective prevention, preparedness, and response.
- ❖ Department of Atomic Energy (DAE) Emergency Infrastructure:
  - Maintains a 24×7 Emergency Control Room at Anushakti Bhavan, Mumbai, with a standby at NPCIL Headquarters, Vikram Bhavan.
  - Serves as the National Contact Point for public radiological/nuclear emergencies and the IAEA National Warning Point.
  - Operates 25 Radiation Emergency Response Centers (RERCs) nationwide for rapid and effective response.

## References (Adapted from)

- Official website of NDMA (<https://ndma.gov.in/>)
- National Disaster Management Plan, 2019
- NDMA (2019) National Disaster Management Manual on Medical Management of Nuclear and Radiological emergencies ([https://ndma.gov.in/sites/default/files/PDF/Technical%20Documents/Medical-Management\\_final.pdf](https://ndma.gov.in/sites/default/files/PDF/Technical%20Documents/Medical-Management_final.pdf))
- Image:
  1. Fig.no. 5.1 (NDMA)
  2. Fig.no. 5.2 (<https://dae.gov.in/nuclear-controls-and-planning-wing-ncpw/ncpw-structure/crisis-management-group-cmg/>)

## Suggested Reading

- NDMA (2019) National Disaster Management Manual on Medical Management of Nuclear and Radiological emergencies ([https://ndma.gov.in/sites/default/files/PDF/Technical%20Documents/Medical-Management\\_final.pdf](https://ndma.gov.in/sites/default/files/PDF/Technical%20Documents/Medical-Management_final.pdf))
- Strengthening institutional resilience for radiation emergency management in India ([https://ndma.gov.in/sites/default/files/PDF/Dr\\_Dinesh\\_Aswal\\_Member\\_NDMA\\_Article.pdf](https://ndma.gov.in/sites/default/files/PDF/Dr_Dinesh_Aswal_Member_NDMA_Article.pdf))

## Chapter 6

### Radiation Therapy and Industrial Radiography

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand Radiation therapy
- Learn general radiation safety measures and best practices.
- Identify key hazards associated with industrial radiography and medical use of radiation.
- Recognize the structure and function of radiography camera.
- Apply safety protocols and handle emergencies effectively.

#### Part A – Radiation Therapy

##### 1. Introduction

The use of ionizing radiation has revolutionized both medicine and industry. In healthcare, radiation is an indispensable tool in diagnosing and treating diseases, especially cancer. In the industrial sector, radiation is crucial in inspecting the integrity of materials and structures without causing damage. However, exposure to ionizing radiation can pose serious health risks to occupational workers if not managed properly. Therefore, ensuring radiation safety is of paramount importance.

##### 2. Radiation Therapy (RT)

- ❖ Radiation therapy (RT) is the medical use of high-energy radiation to destroy or control malignant cells. It works by damaging the DNA of cancer cells, thereby inhibiting their ability to replicate and grow. RT is used either as a primary treatment or in combination with surgery or chemotherapy.

- ❖ The property of ionizing radiation of 'cell kill' is used to eliminate malignant cells effectively. Radiotherapy may serve different treatment intentions depending on the clinical scenario. It is used for curative or adjuvant cancer treatment. The precise treatment intent (curative, adjuvant, therapeutic, or palliative) depends on the tumor type, location, and stage, as well as the general health of the patient.

### 2.1. Clinical-Biological Basis of Radiation Therapy of Tumors

- ❖ The therapeutic use of ionizing radiation is based on its biological action — the ability to cause changes in cells, tissues, organs, and the body as a whole, which depends on the amount of absorbed dose (D). The dose deposited to irradiated tissues is measured in gray (Gy).
- ❖ Shaped radiation beams are aimed from several angles of exposure to intersect at the tumor, yielding a much larger absorbed dose at the desired location than in the surrounding healthy tissue. This technique helps to spare normal tissues from unnecessary exposure.
- ❖ In radiation therapy, the amount of radiation applied varies depending on the type and stage of cancer being treated. Typical fractionated dose for a solid epithelial tumor ranges from 60 to 80 Gy.
- ❖ Whereas lymphomas are treated with 20 to 40 Gy and preventive (adjuvant) doses are typically around 45–60 Gy in 1.8–2 Gy fractions (for breast, head, and neck cancers).
- ❖ The effectiveness of radiation therapy depends on several biological factors:
  - **Radio-sensitivity:** Tumor cells are generally more sensitive to radiation than normal cells.
  - **Oxygen Effect:** Well-oxygenated tissues are more responsive to radiation due to enhanced DNA damage.
  - **Cell Cycle:** Cells are most vulnerable to radiation during mitosis and least sensitive during the Synthesis (S) phase. Understanding these principles helps in optimizing radiation dose and treatment schedules.

### 2.2. Dose Fractionation

- ❖ **Fractionation is defined as a planned division of total dose over time to exploit differences in repair capacity between tumor and normal tissues. (BARC)**

- ❖ IAEA defines fractionation as the practice of splitting the prescribed total dose into several smaller doses over a number of days to allow normal tissue recovery while maintaining tumor control.
- ❖ Fractionation refers to dividing the total radiation dose into several smaller doses delivered over multiple sessions. This technique allows healthy tissues to recover between treatments while maintaining cumulative damage to cancer cells.
- ❖ Fractionated dosing leverages several biological mechanisms that improve tumor control while protecting healthy tissue. Malignant cells are generally less efficient at repairing radiation-induced DNA damage between fractions compared to normal cells. Fractionation also allows tumor cells that were in a relatively radio-resistant phase of the cell cycle (such as the S phase) during one session to progress into more radiosensitive phases (like G2/M) by the next dose. Additionally, tumor hypoxia, which limits radiation efficacy, can be partially reversed between treatments as cells re-oxygenate, increasing the susceptibility of these previously resistant cells to subsequent doses.

### 2.3. Types of Radiation Therapy

Radiotherapy can be classified into several types based on the method of radiation delivery:

**2.3.1 External Beam Radiotherapy (EBRT):** Delivers high-energy X-rays or electron beams from outside the body using machines like linear accelerators (LINACs). It is non-invasive and highly precise.

**2.3.2 Electron Beam Accelerators (EBAs):** a device that uses high-voltage electric fields to accelerate electrons to high energies, which can then be used for industrial, medical, and research purposes.

- ❖ **Industrial:** Sterilization of medical devices, food irradiation, polymer modification, curing of coatings, treatment of wastewater, sewage sludge and industrial effluents. Example - Isotope of Californium ( $Cf^{252}$ ) is used in the airlines to detect explosives in the luggage. Isotope of Americium ( $A^{241}$ ) is used in many industries as a Smoke Detector

- ❖ **Medical:** Cancer radiotherapy, as in Medical Linear Accelerator (LINAC), intraoperative radiation therapy. A LINAC is a sophisticated machine that accelerates electrons to produce high-energy X-rays for treating deep-seated tumors. LINACs allow for precise targeting, adjustable dose delivery, and integration with imaging systems for guidance.
- ❖ **Research:** Materials testing, radiation damage studies.



Fig.no. 6.1- External Beam Radiation Therapy

**2.3.3 Tele therapy:** A form of EBRT where the radiation source (e.g., Cobalt-60 - Tele cobalt) is placed at a distance from the body. This method is used extensively in resource-limited settings.

**2.3.4 Brachytherapy (Sealed Source Radiotherapy):** It involves placing a sealed radioactive source inside or adjacent to the tumor. It can be:

- ❖ **Temporary:** Sources are inserted and then removed after a specific duration (e.g., HDR brachytherapy).
- ❖ **Permanent:** Sources are implanted and remain in the body (e.g., prostate seed implants).

**2.3.5 Systemic Radioisotope Therapy (Radiopharmaceuticals):** It involves the administration of unsealed radioactive substances either by intravenous infusion or oral ingestion. These

radiopharmaceuticals travel through the bloodstream to target specific tissues (e.g., I-131 for thyroid cancer). Depending on the type of radiation that those radioisotopes produce, they can be used to diagnose or treat several medical conditions, imaging of many different organs, such as brain, heart, kidney and bone, to the treatment of cancer and hyperthyroidism. Examples:

- ❖ Isotopes like **Ruthenium-106 (Ru-106)** for eye cancer treatment and **Yttrium-90 (Y-90)** derived from nuclear waste for other cancer therapies.
- ❖ Radioisotopes such as Iodine-125, Iodine-131, Lutetium-177, Samarium-153, and Strontium-89, are used for diagnostic and therapeutic applications. For eg. **Strontium-89** is used for cancer treatment including palliative care of bone metastatic cancer

### 2.3.6 Principles of Radiotherapy

- ❖ **Optimal Tumor Dose:** Delivering a precise and effective radiation dose to the tumor to maximize treatment efficacy.
- ❖ **Protection of Healthy Tissue:** Minimizing radiation exposure and damage to surrounding healthy organs and tissues.
- ❖ **Stimulation of Body's Protective Mechanisms:** Employing strategies that support and enhance the body's natural repair and defense mechanisms during treatment.

### 2.3.7 Protection of the Patient

- ❖ Ensuring patient safety in radiotherapy requires a comprehensive approach that minimizes exposure to healthy tissues while delivering the prescribed dose to the target area.
- ❖ This includes accurate imaging and treatment planning using CT or MRI-based techniques to precisely define tumor boundaries.
- ❖ Non-target areas are shielded to reduce unnecessary radiation exposure.
- ❖ Verification of dose delivery is performed to ensure that the planned dose matches the actual treatment. Immobilization devices are employed to maintain consistent patient positioning throughout therapy sessions, and ongoing monitoring is conducted to detect and manage any treatment-related toxicity promptly.

### **2.3.8 Radiation Safety Monitoring Equipment**

- ❖ Radiation safety in medical and industrial settings relies on a range of monitoring and protective equipment.
- ❖ Personal dosimetry is performed using TLDs (Thermoluminescent Dosimeters) or Optically Stimulated Luminescence (OSLs) dosimeters to track individual exposure. Ionization chambers are used for precise calibration of radiation-emitting machines.
- ❖ Survey meters help assess radiation levels in treatment or work areas, ensuring environmental safety.
- ❖ Interlock systems are installed to prevent accidental exposure by automatically shutting down equipment if safety conditions are not met.
- ❖ Additionally, lead aprons, shields, and other personal protective equipment (PPE) are employed to protect staff from stray radiation.

## **Part B - Industrial Radiography**

### **1. Introduction**

Industries use a testing method called “radiography” to check for defects e.g., cracks, lack of penetration, porosity, inclusion, pinholes) in metal parts and welds to ensure safety /durability and quality in the products in a Non-Destructive manner (NDT). Testing on gas /oil pipelines in the field is called “open field radiography”. Industrial radiography uses either x-rays or gamma rays. X-ray radiography is generally used in a fixed location. Here, radiation hazards exist only when this equipment is turned on. Industrial radiography devices using radioactive sealed source emit gamma rays and are portable. There is an inbuilt shielding to protect workers from the radiation in both types of equipment.

### **2. Industrial Radiographic Testing (IRT)**

- ❖ Industrial Radiographic Testing (IRT) is a non-destructive testing (NDT) technique that uses ionizing radiation (commonly X-rays or gamma rays) to inspect the internal structure of materials, welds, and components for defects without causing damage.
- ❖ IRT involves exposing a component to radiation and capturing an image using photographic film or digital sensors.
- ❖ Defects such as cracks or voids become visible due to differential absorption of radiation.
- ❖ Types of radiation used in industrial radiography are X-rays and gamma sources (such as  $^{192}\text{Ir}$ ,  $^{137}\text{Cs}$ ,  $^{75}\text{Se}$  and  $^{60}\text{Co}$ ).
- ❖ Trained and certified personnel handle and operate the sources and use certified exposure devices.

### **3. Radiography Camera and Pigtail**

- ❖ The industrial radiography devices are commonly referred to as cameras, and they are classified as either Gamma cameras or X-ray cameras. With radiography, we obtain internal information about a material simply by taking an image, without breaking or damaging the object.

❖ Radiography cameras are key tools in industrial non-destructive testing (NDT), enabling the internal inspection of materials without damage. These cameras utilize ionizing radiation—either from radioactive sources or X-ray tubes—to create radiographic images of welds, castings, pipelines, and structural components.

❖ **Types:**

### 3.1 Industrial gamma radiography exposure device (IGRED) / Gamma cameras

Industrial gamma radiography exposure devices (IGRED), commonly known as gamma cameras, are non-destructive testing (NDT) tools used to detect defects in materials such as welds, castings, and building components. These devices house sealed radioactive sources, typically **Iridium-192 (Ir-192)** or **Cobalt-60 (Co-60)**, and are designed to be compact, portable, and suitable for use in field conditions.

❖ **Key Features and Functions:**

- Constructed with high-density shielding materials (e.g., depleted uranium or lead) encased in steel or alloy for robust protection.
- The radioactive source capsule is securely stored within the device when not in use.
- Radiation is emitted only when the source is extended into the exposure position via a drive mechanism, such as a pigtail and crank assembly.
- After testing, the source is retracted into the shielded container to prevent further emission.
- Modern gamma cameras are equipped with interlock systems, source position indicators, and are type-approved by regulatory authorities to ensure safety and compliance.

❖ **Safety Considerations:**

- Use of certified equipment and routine inspections to check for source leakage or mechanical faults.
- Strict adherence to the principles of **time, distance, and shielding** to minimize exposure.
- Operators must undergo formal training and certification by competent authorities such as **BARC** or **AERB** to ensure safe handling and operational competence.

### 3.2 X-ray Cameras

X-ray cameras, also referred to as X-ray generators, produce ionizing radiation by accelerating electrons to strike a target material, typically tungsten. Unlike gamma cameras, they do not rely on radioactive sources and can be completely turned off when not in use. In X-ray radiography, radiation is generated only when the machine is switched “ON,” and no radiation persists once the power is turned off.

#### ❖ Key Features and Benefits:

- Electrically powered and controlled via software or remote consoles.
- Allow on-demand radiation generation, with no residual activity when turned off.
- Ideal for laboratory or manufacturing environments with a stable power supply.
- Simplified operation compared to devices using radioactive sources, reducing regulatory complexity.

#### ❖ Limitations:

- Generally, less portable than gamma cameras.
- Depend on a consistent electrical supply and controlled environmental conditions.
- Produce lower energy radiation than some gamma sources, limiting penetration in thick or dense materials.

#### ❖ Safety Measures:

- X-ray rooms must be shielded in accordance with national safety standards.
- Warning signals, interlock systems, and controlled access must be in place to prevent accidental exposure.
- Routine dose monitoring and preventive maintenance are essential to ensure long-term operational safety.

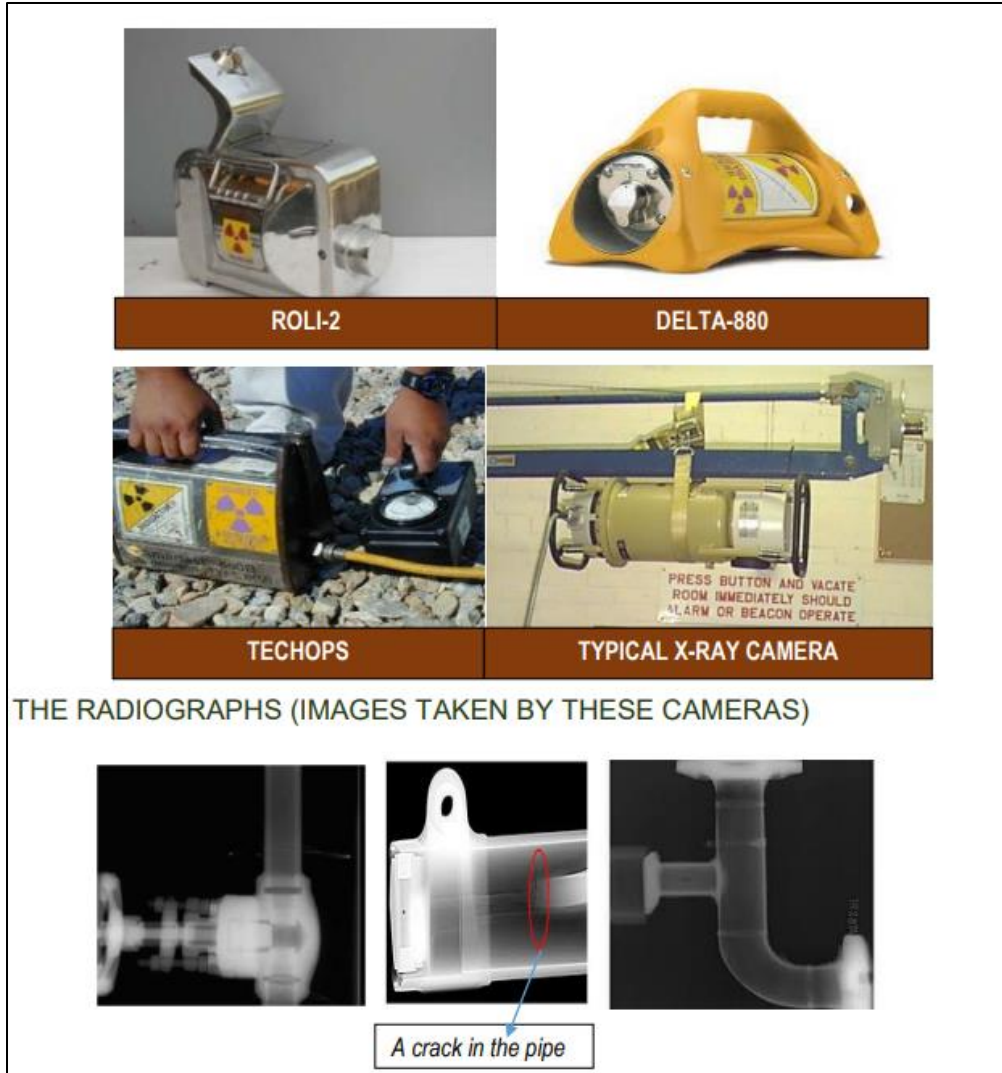


Fig.no. 6.2 - Industrial Radiography Camera and their images

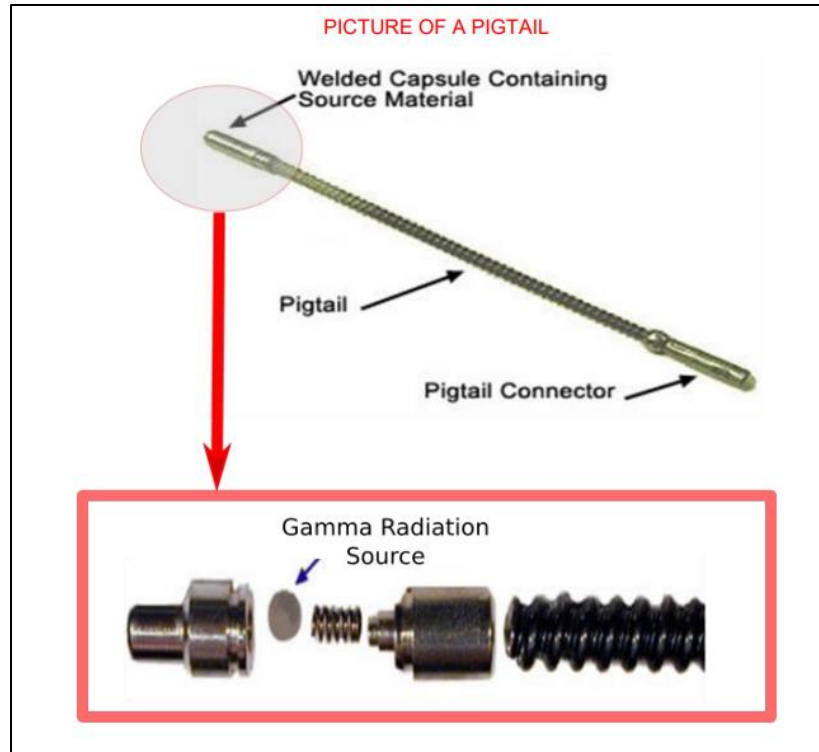


Fig.no. 6.3 - Pigtail

### 3.3 Pigtail (Source Assembly Cable)

- ❖ The **pigtail** is a flexible stainless steel cable that connects the radioactive source capsule to the crank mechanism of a gamma camera, allowing controlled movement of the source in and out of the device. Faults in the pigtail or improper handling are among the most common causes of overexposure incidents in industrial radiography.
- ❖ **Functions and Features:**
  - Enables safe remote handling of the radioactive source.
  - Typically housed within a guide tube that channels the pigtail and source to the exposure area.
  - Must be mechanically strong, corrosion-resistant, and securely attached to prevent detachment of the source.

#### ❖ **Safety Concerns:**

- The pigtail is a critical component; failure or damage can lead to **source-stuck scenarios**, which are major radiation emergencies.
- Regular inspection, lubrication, and maintenance are mandatory, as per **AERB** and **BARC** guidelines.
- Handling should only be performed by trained and certified personnel under supervision.

#### ❖ **Occupational Risks:**

- High radiation exposure if the source is not properly retracted.
- Accidental exposure due to equipment malfunction or human error.
- Long-term health effects may include skin burns, sterility, cataracts, or cancer.

#### ❖ **Emergency Precautions:**

- The gamma source continuously emits radiation, even when not actively in use.
- In case the source becomes exposed due to mechanical failure:
  - Move away immediately.
  - Do **not** touch the source.
  - Alert trained personnel to retrieve and shield the source safely.

#### ❖ **Summary:**

Gamma and X-ray cameras are vital for industrial radiography, providing precise internal imaging without damaging structures. While X-ray cameras offer operational flexibility, gamma cameras are more portable and field-ready. The pigtail is essential for safe source manipulation, and strict adherence to national and international safety standards ensures protection of workers and the environment.

## 4. **Radiation Safety Instructions**

#### ❖ **General guidelines**

- Always maintain a safe distance from an active camera.
- Strictly follow standard operating procedures.
- Use appropriate shielding and remote handling tools whenever operating the device.
- Ensure area signage is visible and access is controlled to prevent unauthorized entry.

❖ **Do's**

- Wear personal dosimeters and ensure they are properly positioned.
- Verify that interlocks, safety alarms, and other protective systems are functional before use.
- Participate in regular radiation safety training courses.

❖ **Don'ts:**

- Never bypass or disable safety devices.
- Do not hold or directly approach the radioactive source.
- Avoid working in radiation zones without proper authorization, training, and protective measures.

## 5. Radiography Locations

- **Enclosed Facility Radiography:** Usually performed in rooms with thick concrete walls to provide adequate shielding and control radiation exposure.
- **Open Field Radiography:** Conducted outdoors, for example during non-destructive testing (NDT) of gas or oil pipelines in the field.
- **Shop-floor Radiography:** Sometimes carried out within designated areas on the factory shop floor, with safety measures in place to protect workers and the public. In industrial radiography, “shop-floor radiography” refers to performing radiographic testing within the production area itself, rather than in a separate, purpose-built radiography room. Because other workers may be nearby, special safety measures are required — such as temporary barriers, warning signs, radiation survey monitoring, and controlled access — to ensure exposure stays within permissible limits (as per AERB safety code).

## 6. Uses of Industrial Radiography

Atomic energy has applications across multiple sectors including agriculture, healthcare, food preservation, defence, water treatment, and electricity generation. It also ensures the structural integrity, safety, and quality of industrial products across diverse sectors.

- **Weld Inspection:** Detects flaws such as cracks, porosity, and incomplete fusion in pipelines and structural joints.
- **Casting and Forging Examination:** Identifies blowholes, shrinkage cavities, and inclusions in metal parts.
- **Oil, Gas, and Petrochemical Industries:** Inspects pipelines and plant components under high-stress conditions.
- **Aerospace and Aviation:** Evaluates turbine blades, airframes, and composite materials for defects.
- **Power and Nuclear Energy:** Assesses critical components in nuclear reactors and thermal plants. India generated 56,681 million units (MUs) of nuclear electricity in 2024–25.
- **Shipbuilding and Marine Structures:** Ensures quality of hull welds and submerged structures.
- **Construction and Infrastructure:** Examines bridges, reinforced concrete, and building frameworks.
- **Manufacturing and Fabrication:** Used in automotive, tooling, and heavy machinery sectors for quality control.



Fig.no.6.4- A setup showing a radiography camera in operation near a large pipeline structure

- ❖ Industrial radiography accidents often occur due to poor source security, equipment failure, or human error. They highlight the importance of time–distance–shielding, training, dosimetry, equipment maintenance, and regulatory oversight to prevent severe radiation injuries and fatalities.

**7. Case Study: Industrial Radiography Accident – Samut Prakan, Thailand (24 January 2000)**



Fig.no. 6.5 - A response team member using tongs to place the retrieved Co-60 radioactive source in a shielded container

**7.1 Background:** A **Cobalt-60 industrial radiography source** (activity ~15 TBq) was improperly discarded and ended up in a junkyard in Samut Prakan, near Bangkok. The source was removed from its shielding and handled by workers who were unaware of its danger.

**7.2 Accident Details:** Workers and scrap dealers dismantled the device, exposing themselves and others to very high doses of gamma radiation. No safety labeling or regulatory control was in place at the time of the accident.

**7.3 Causes:**

- Abandonment of a high-activity source without regulatory oversight.
- Lack of awareness among the public and workers handling the material.

**7.4 Health Effects:**

- Ten individuals received significant radiation exposure.
- Three deaths occurred from acute radiation syndrome (ARS).
- Survivors experienced severe radiation burns, long-term health effects, and psychological trauma.

**7.5 Regulatory/Preventive Lessons:**

- Strengthening of national regulations on radiation source control.
- Implementation of IAEA Code of Conduct on the Safety and Security of Radioactive

**7.6 Sources:** Stress on public education, secure disposal pathways, and strict IAEA safety compliance for industrial radiography.

Radiation is a powerful tool that demands careful management. Whether in therapeutic medicine or industrial testing, the safety of workers and patients must be paramount. This can be achieved through strict adherence to guidelines set by IAEA, WHO, AERB, and BARC, comprehensive training programs, and the consistent use of radiation monitoring and protective equipment. The lessons of the past, such as the Radium Girls, remind us of the human cost of neglecting safety and the enduring importance of vigilance in occupational radiation use.

## 8. Case study: The Radium Girls (1917–1926, USA): A Tragic Lesson in Occupational Radiation Exposure

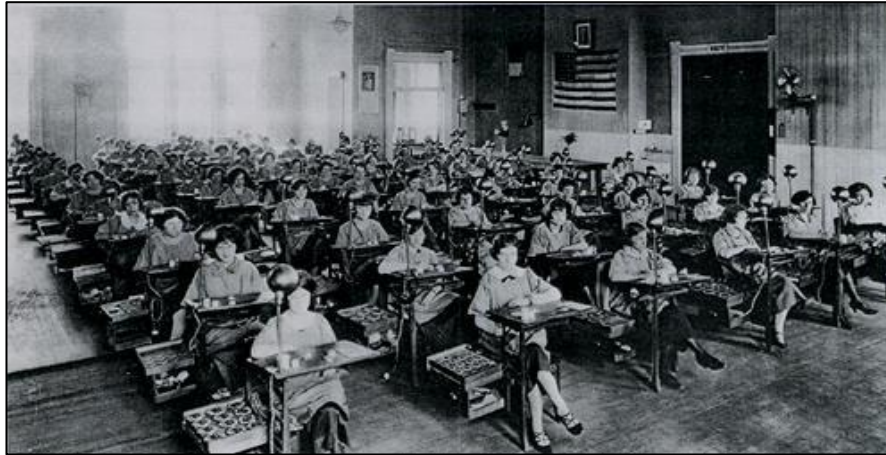


Fig.no. 6.6 – Radium Girls

**8.1 Background & Discovery:** In 1898, Radium was discovered by Marie and Pierre Curie. It quickly became celebrated for its luminescent and therapeutic properties.

### 8.2 Medical and Commercial Use:

- From 1900 to 1930, Radium therapy was marketed for treating arthritis, stomach disorders, and even cancer, and was endorsed by the American Medical Association.
- During World War I, radium-based paint was used to create glow-in-the-dark dials for military watches and instruments.

### 8.3 Occupational Exposure:

- The "Radium Girls" were a group of young female factory workers in the United States during the 1910s and 1920s who painted watch and instrument dials with self-luminous radium-based paint. They were instructed to "lip-point" their brushes—shaping the tips with their lips—unknowingly ingesting small amounts of radium-226 each time.

#### **8.4 Health Effects:**

- Over time, many developed severe health problems including jaw necrosis (radium jaw), anaemia, bone fractures, and ultimately bone cancers (osteosarcomas), particularly sarcomas of the skull and femur.
- The underlying mechanism was the selective accumulation of radium in bone, where it emitted alpha radiation, damaging bone marrow and surrounding tissues.

#### **8.5 Legal and Regulatory Aftermath**

- Late 1920s – A group of afflicted women, known as the "Radium Girls," sued the company. Despite initial resistance, they won compensation, which brought national attention to the dangers of occupational radiation exposure.
- The Radium Girls case was pivotal in demonstrating the carcinogenic potential of internal alpha emitters and led to major reforms in occupational health and radiation protection standards, including the establishment of the U.S. Occupational Safety and Health Administration (OSHA) decades later.

#### **8.6 Lessons Learned:**

The case study on Radium Girls highlighted the importance of:

- Protective measures and safety training in radiation work
- Early regulations on exposure limits
- Worker rights and employer accountability in hazardous environments

### Take Home Message:

- ❖ Radiation aids in medical treatment and industrial testing.
- ❖ Radiation therapy uses ionizing radiation for cancer treatment with curative, adjuvant, and palliative roles.
- ❖ Dose fractionation allows tumor control while sparing normal tissues through repair, re-assortment, and re-oxygenation.
- ❖ Types of radiotherapy include external beam, brachytherapy, and systemic radiopharmaceuticals, guided by ALARA principles.
- ❖ Industrial radiography (using gamma/X-rays) is vital for non-destructive testing but carries high occupational risk.
- ❖ Industrial radiography is among the highest-risk occupational uses of radiation. Accidents can affect both workers and the public.
- ❖ Radiation benefits medicine, industry, and agriculture, but strict safety standards and monitoring are essential to protect workers.

### References: (Adapted from)

- IAEA (1996) Radiation dose in radiotherapy from prescription to delivery ([https://www-pub.iaea.org/MTCD/Publications/PDF/te\\_896\\_prn.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/te_896_prn.pdf))
- IAEA (Radiotherapy equipments) (<https://www.iaea.org/resources/hhc/medical-physics/radiotherapy/equipment>)
- AERB Radiation Safety in Industrial Radiography. (<https://www.aerb.gov.in/english/regulatory-facilities/radiation-facilities/application-in-industry/industrial-radiography>)
- IAEA. (2011). Radiation Safety in Industrial Radiography: Safety Guide SSG-11. ([https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1466\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1466_web.pdf))
- AERB. (2011). Safety Code for Industrial Radiography (AERB/NF/SC-1).

- BARC. (2020). Training Manual for Radiological Safety Officers in Industrial Radiography.
- IAEA (2003). Occupational Radiation Protection. ([https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1145\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1145_web.pdf))
- IAEA. (2003). Manual on Radiation Protection in Industrial Radiography (Training Course Series No. 21).
- AERB, Basic Radiation Safety in Industrial Radiography - Information for Auxiliary Staff (<https://www.aerb.gov.in/images/PDF/brsir.pdf>)
- IAEA (2002) The Radiological Accident in Samut Prakan.
- IAEA (2015) Preparedness and Response for a Nuclear or Radiological Emergency. IAEA Safety Standards Series No. GSR Part 7.
- WHO (2006). Health Effects of Radiological Accidents.
- United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources and Effects of Ionizing Radiation, UNSCEAR 2008 Report.
- Image:
  1. Fig.no. 6.1 (National Cancer Institute)
  2. Fig.no. 6.2,6.3 [AERB, Basic Radiation Safety in Industrial Radiography - Information for Auxiliary Staff (<https://www.aerb.gov.in/images/PDF/brsir.pdf>)]
  3. Fig.no.6.4 (<https://besgroup.com/services/testing/non-destructive-testing/radiography/>)
  4. Fig.no.6.5 ([https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1124\\_scr.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1124_scr.pdf))
  5. Fig.no. 6.6 ('Radium Girls' by Martha Irvine, Associated Press, Buffalo News, 1998)

## Suggested Reading

- Atomic Energy Regulatory Board (AERB). Radiation Safety in Industrial Radiography. (<https://www.aerb.gov.in/english/regulatory-facilities/radiation-facilities/application-in-industry/industrial-radiography>)
- IAEA. (2011). Radiation Safety in Industrial Radiography: Safety Guide SSG-11. ([https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1466\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1466_web.pdf))
- IAEA (2003). Occupational Radiation Protection. ([https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1145\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1145_web.pdf))
- IAEA (2005) Radiation Oncology Physics: a handbook for teachers and students ([https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1196\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1196_web.pdf))

## Chapter 8

### Orphan Sources and RDD / Dirty Bomb

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand the risks associated with radioactive sources
- Identify causes and dangers of orphan sources
- Compare RDD to nuclear weapons
- Learn about Possible Steps to Minimize the RDD Threat
- Understand the Challenges in Management of radiological terrorism

#### 1. Introduction

- ❖ Radioactive sources (including sealed sources, i.e. sources that are permanently sealed in a capsule or closely bonded and in a solid form) are used widely throughout the world in a variety of medical, industrial, research and military applications.
- ❖ **An orphan source is a radioactive source that is not under regulatory control, either because it has never been under regulatory control or because it has been abandoned, lost, misplaced, stolen or otherwise transferred without proper authorization. (IAEA)**
- ❖ Orphan sources have led to accidents with serious, even fatal, consequences as a result of the exposure of individuals to radiation.
- ❖ The melting of an orphan source with scrap metal or its rupturing when mixed with scrap metal has also resulted in contaminated recycled metal and wastes. If this happens, expensive cleanup operations may be necessary.
- ❖ If the contaminated material is not detected at the metal recycling and production facility, workers may be exposed to radiation and radionuclides may become incorporated into various

finished products and wastes, which, in turn, may lead to the exposure of users of these products

## **2. Causes and Management of Orphan Sources**

### **2.1 Causes of Orphan Sources:**

Orphan sources—radioactive materials that are lost, abandoned, or outside regulatory control—can arise due to:

- Inadequate regulatory oversight.
- Improper labeling or loss during transportation.
- Abandonment following facility shutdowns.
- Theft or pilferage, often for scrap.
- Natural disasters that disrupt storage or transport.

### **2.2 Optimal Storage of Radioactive Sources:**

To prevent orphan sources, proper storage practices are essential:

- Use shielded enclosures clearly marked with warning signs.
- Store sources in secured rooms with controlled access.
- Maintain accurate records and conduct regular audits.
- Ensure timely return or disposal of sources according to regulatory protocols.

### **2.3 Potential Dangers of Orphan Sources:**

Orphan sources pose significant risks, including:

- Accidental exposure to individuals, such as scrap yard workers.
- Environmental contamination through improper handling or disposal.
- Potential use in radiological dispersal devices (RDDs) by non-state actors.
- Economic losses from clean-up operations and evacuation measures.
- Public fear and mass panic due to perceived radiation hazards.

Proper regulatory control, secure storage, and awareness are critical to minimizing these risks and ensuring public and occupational safety.

## 2.4 Case Examples:

**Goiania, Brazil (1987):** Radiotherapy (Medical teletherapy) unit source, <sup>137</sup> Cesium (50.9 TBq), was abandoned in a private radiotherapy clinic. Scrap metal scavengers dismantled it, spreading powdery cesium (Cs) chloride across the city, which caused severe injuries and deaths. The glowing blue powder fascinated the public; several people handled, shared, and even applied it to their skin.

### ❖ Consequences:

- >100,000 people monitored,
- 250 contaminated.
- 4 deaths
- 112,000 people screened
- Widespread environmental contamination of homes, soil, and scrap yards.

### ❖ Lesson Learnt:

- The Goiânia accident demonstrated that uncontrolled radioactive sources can cause severe health, social, and environmental consequences, emphasizing the need for strong regulatory frameworks, secure source management, and community awareness.
- Importance of strict control and security over radioactive sources (“orphan source” problem).
- Need for public awareness about radiation hazards and hazard symbols.
- Highlighted the role of regulatory authorities (IAEA Code of Conduct later strengthened).
- Showed necessity of emergency preparedness, decontamination capability, and medical response in radiation accidents.

Box 8.1- Example of Orphan source incident

**Mayapuri, India (2010):** A Co-60 source led to one death and several injuries.

- **Cause:** Orphan source (Cobalt-60) sold as scrap and handled unknowingly.
- **Impact:** One fatality, several radiation injuries.
- **Lessons:** Strengthened source tracking, licensing, and disposal practices.

### Box 8.2 Example of Orphan source incident

## 3. Radiological Dispersal Device (RDD) / Dirty Bomb

### 3.1 Introduction:

- ❖ A Radiological Dispersal Device (RDD)—also known as a radiological weapon or dirty bomb—is designed to intentionally spread radioactive material using conventional explosives, without causing a nuclear detonation.
- ❖ Unlike true nuclear weapons, RDDs do not produce a nuclear explosion or significant explosive yield. Instead, they disperse radioactive substances such as spent nuclear fuel or radioactive waste, aiming to cause casualties, contaminate the environment, and disrupt public and economic activities.
- ❖ RDDs are considered a major security concern because a radioactive source can be maliciously incorporated into a conventional explosive. While the explosion itself causes immediate physical damage, the spread of radioactive material typically results in low radiation doses for the public and is unlikely to cause mass radiation fatalities. However, such an incident can trigger widespread panic, psychological impact, environmental contamination, long-term cleanup challenges, and substantial economic losses—especially if critical areas like commercial centers, airports, or rail yards are affected.
- ❖ Given these risks, international agencies such as the IAEA and WHO, along with national regulatory authorities including AERB, BARC, and the Nuclear Regulatory Commission (NRC),

emphasize stringent security, tracking, and control of radioactive sources to prevent their misuse in RDDs.

### 3.2 Attempted RDD/ Dirty Bomb Incident:

- ❖ **2002 Chechen Plot, Russia:** Authorities discovered and prevented a planned dirty bomb attack that intended to use radioactive cesium or cobalt. The intervention avoided potential radiological contamination and public exposure, underscoring the need for strict control, secure storage, and monitoring of radioactive sources, as well as the importance of preparedness and rapid response to radiological threats.

### 3.3 Phases after RDD attack

After an RDD attack, the response is structured into **three phases** to manage immediate hazards, stabilize the situation, and restore normalcy:

- ❖ **Immediate Phase (24–48 hours)**
  - Focuses on **saving lives and controlling exposure**.
  - Actions include rescuing injured individuals, providing emergency medical care, evacuating people from contaminated areas, and securing the site to prevent further exposure. This phase prioritizes **rapid intervention** to minimize harm from both the blast and radioactive contamination.
- ❖ **Intermediate Phase (48–100 hours)**
  - Focuses on **stabilization and containment**.
  - Activities include setting up control zones (hot, warm and cold zones), shielding areas (to attenuate radiation and protect workers, emergency responders, or the public during a radiological incident), assessing contamination in air, soil, and water, preventing further spread of radioactive materials, and protecting people through decontamination and monitoring. The goal is to **limit additional exposure** and understand the scope of contamination.
- ❖ **Last Phase (4 days–15 days or longer)**
  - Focuses on **recovery, cleanup, and returning to normal life**.

- Key steps include large-scale decontamination of buildings, streets, and vehicles, remediation of contaminated property, safe disposal of radioactive waste, and resumption of public services. Additionally, **long-term health monitoring** of affected individuals is essential to detect delayed effects of radiation exposure.

#### ❖ **Immediate Phase (24–48 hours)**

- **Focus:** Emergency life-saving measures and initial control.

- **Key actions** include:

- Rescue and relief of victims (blast and radiation exposure).
- Providing emergency medical care.
- Evacuation of people from contaminated areas.
- Securing the site to limit further exposure.

#### ❖ **Intermediate Phase (48 hours – 100 hours)**

- **Focus:** Stabilization and containment of the situation.

- **Key actions** include:

- Implementing countermeasures (e.g., setting up control zones)
- Assessing the extent of contamination in air, soil, and water.
- Preventing further spread of radioactive materials.
- Monitoring and reducing human exposure (through decontamination and protective measures).

#### ❖ **Last Phase (4 days – 15 days or longer)**

- **Focus:** Recovery, cleanup, and restoration of normalcy.

- **Key actions** include:

- Large-scale decontamination efforts (streets, buildings, vehicles).
- Remediation of contaminated property (removing radioactive dust/debris).
- Disposal of radioactive waste safely.
- Resumption of normal community services (utilities, public transport, schools, workplaces).
- Long-term health monitoring of affected individuals.

Box 8.3- Phases after RDD attack

- **Summary:** These phases ensure a **systematic response**—first addressing immediate danger, then containing the situation, and finally restoring safety and normalcy—while minimizing health risks and environmental contamination.

### 3.4 Comparison to RDD & Improvised Nuclear Device (IND)

Feature	Radiological Dispersal Device (RDD)	Improvised Nuclear Device (IND)
<b>Definition</b>	RDD is a device that scatters radioactive material without a nuclear chain reaction.	IND is a homemade or illicitly assembled nuclear explosive device.
<b>Mechanism</b>	Uses conventional explosives to scatter radioactive material	Nuclear detonation (fission or fusion)
<b>Explosion</b>	Small conventional blast	Massive nuclear blast (massive energy, intense heat and ionizing radiation)
<b>Radiation level</b>	Low to moderate and mostly limited to the area where the material settles.	Extremely high, both prompt radiation (immediate, intense, short duration) and long-term fallout (delayed, from radioactive particles that settle to the ground and persist for hours to years)
<b>Impact</b>	The main impact is localized contamination and fear, not life-threatening radiation doses for most people.	Lethal close to the blast and cause long-term cancers and environmental contamination.
<b>Fatalities</b>	Limited immediate casualties (Unlikely to result in immediate deaths)	Massive immediate casualties from blast, heat, and radiation
<b>Destruction</b>	Minimal structural damage	Widespread destruction over a large area

Table no. 8.1-- Comparison to RDD & Improvised Nuclear Device (IND)

## 4. Radiation Exposure Device (RED)

### 4.1 Introduction

- ❖ RED (hidden source) is a device intended to cause harm by exposing people to radiation without spreading radioactive material. For example: unshielded or partially shielded radioactive material placed in any type of container and in a location capable of causing a radiation exposure to one or more individuals.
- ❖ RED may cause a few deaths, but would not cause widespread contamination. RED may be hidden in public transportation (under a bus or subway seat), a busy shopping mall (the food court, for example), movie theatre, or any other location where a large number of people may sit, stand, or pass close by. Individuals who come in contact with, touch, or sit on a radioactive material container do not become contaminated. The danger is from exposure, for extended periods of time, to high radiation levels close to the radioactive material.



Fig. no.8.1-- RED

- ❖ The figure 8.2 illustrates a concealed radioactive source in a public place (hidden inside a trash bin on the left). The red triangular beam represents the radiation field emitted from the

source, exposing unsuspecting passersby. It emphasizes the invisible danger of radiation exposure in public areas if radioactive sources are not securely stored, controlled, or if deliberately misused.

- **Source placement:** A radiation-emitting object (possibly a sealed source) has been hidden in a dustbin.
- **Radiation field** (red cone): Shows how the ionizing radiation spreads outward, potentially exposing individuals walking nearby.
- **Public exposure risk:** The people in the beam are unknowingly receiving radiation doses.
- **Scenario relevance:** Could represent a malicious act (e.g., a Radiological Dispersal Device (RDD) or “dirty bomb” without explosion). Or an orphan source incident where a misplaced or lost industrial source exposes the public.

#### 4.2 Possible Steps to Minimize the RDD Threat

Minimizing the threat from Radiological Dispersal Devices (RDDs) requires actions in three major areas: prevention, detection, and preparedness.

- ❖ **Control, Secure, and Track Radioactive Materials:** This means making sure radioactive sources are safely stored and protected in places like hospitals, industries, and waste facilities so they cannot be misused. It also includes encouraging the use of safer technologies that do not rely on high-risk radioactive materials. Tracking systems—especially for powerful sources like RTGs—help authorities know where each source is at all times. Recovering orphan sources (lost, abandoned, or uncontrolled radioactive materials) through national and IAEA programs further reduces risk.
- ❖ **Increase Detection of Nuclear Smuggling Attempts:** This involves improving technology that can detect radioactive materials when someone tries to transport them illegally. Portable, low-cost detectors can be used at borders, ports, and checkpoints. Mobile search teams can rapidly respond if suspected material is reported. Strong cooperation between countries helps ensure better information-sharing and cross-border monitoring.
- ❖ **Prepare for Response to an RDD Event:** Even with prevention and detection, preparedness is essential. Emergency plans must clearly define who is in charge and how communication will

flow during an incident. First responders need training in radiation triage, protective measures, and decontamination. Finally, effective strategies must be developed for cleaning up contaminated urban areas, which is often the most challenging part of an RDD response.

❖ **Control, Secure, and Track Radioactive Materials**

- Strengthen security of large source sites (including hospitals, industries, and waste facilities).
- Promote alternative technologies (e.g., electron accelerators replacing sealed sources).
- Implement tracking technologies for high-risk sources (e.g., Radioisotope Thermoelectric Generators – RTGs).
- Support orphan source recovery and safe disposal through IAEA and national programs.

❖ **Increase Detection of Nuclear Smuggling Attempts**

- Enhance radiation detection technologies (portable, cost-effective, reliable).
- Develop mobile search and response teams to rapidly investigate and intercept illicit material.
- Strengthen international collaboration for cross-border detection and response.

❖ **Prepare for Response to an RDD Event**

- Establish emergency response plans with clear command and communication protocols.
- Train first responders in triage, decontamination, and protective measures.
- Develop effective decontamination strategies and technologies for urban environments.

Box 8.4- Possible Steps to Minimize the RDD Threat

**4.3 Response to Unexploded RDD:**

- ❖ **Initial detection & scene assessment:** As soon as an unexploded device is suspected, the scene must be evaluated for radiological hazards. Early monitoring of dose-rates, contamination and potential dispersion is critical.
- ❖ **Establish secure cordons and control zones:** The area around the device should be divided into zones (hot, warm, cold) to separate areas of highest hazard (unexploded device and

nearby), support operations (response staging), and protect the public. These zones must be dynamically adjusted based on measured conditions.

- ❖ **Protect first responders and the public:** Response teams must don appropriate protective equipment, follow radiological safety protocols (time, distance, shielding, contamination control), and ensure that any intervention does not inadvertently trigger the device or spread contamination further.
- ❖ **Device mitigation / render safe procedures:** Specialists (bomb disposal squad and radiological experts) must engage to safely disable or remove the unexploded device. All actions must account for both the conventional explosive risk and the radiological hazard of the source material.
- ❖ **Contamination control and monitoring:** Following device mitigation, the site must be surveyed for residual radioactive contamination. Contamination may be spread due to an attempted dispersal or partial failure of the device. Mapping and measuring contamination helps shape subsequent protective actions (shelter, evacuation, decontamination).
- ❖ **Protective actions for the affected population:** Depending on contamination, protective measures may include: sheltering in place, evacuation, food/water restrictions, and public communications. Decisions must balance radiological risk with other hazards (e.g., explosion damage, structural risks).
- ❖ **Decontamination and recovery:** After the device is rendered safe and contamination surveyed, decontamination of surfaces, infrastructure, and potentially evacuees or public areas must be planned and executed. Long-term monitoring of the site may be required.
- ❖ **Communication and coordination:** Clear lines of command and communication — between radiological experts, bomb disposal units, first responders, emergency management agencies and public health authorities — are essential. Public information must be managed to minimize panic and misinformation.
- ❖ **Post-incident evaluation and lessons learned:** Once immediate risks are mitigated, a detailed review of the incident response (what worked, what didn't) should be undertaken to inform future preparedness plans, training, equipment procurement, and inter-agency coordination.

## 5. AERB's Role in Radiation Safety:

- ❖ The **Atomic Energy Regulatory Board (AERB)** is India's primary authority responsible for ensuring radiation safety. Its core functions include:
  - Licensing and regulating the use of radioactive materials.
  - Conducting inspections and enforcing compliance with safety regulations.
  - Promoting public awareness and providing training on radiation safety.
  - Coordinating with security and emergency agencies during radiological incidents.
  - AERB mandates include:
    - Implementation of safe disposal procedures for radioactive sources.
    - Regular audits and continuous tracking of all radioactive materials.
    - Investigation and management of lost, stolen, or orphan sources to prevent accidental exposure or misuse.
  
- ❖ Through these measures, AERB ensures protection of workers, the public, and the environment from radiation hazards.

## Take Home Message:

- ❖ Orphan Sources: Radioactive materials lost, abandoned, or stolen from regulatory control; commonly arise from industry, medical use, or research, and have caused severe accidents (e.g., Mayapuri, Delhi 2010).
- ❖ Radiological Dispersal Device (RDD/Dirty Bomb): Conventional explosives combined with radioactive sources; causes contamination, fear, economic disruption—rarely immediate deaths from radiation.
- ❖ RDD/Dirty Bomb: Spreads radioactive contamination, psychological and economic effects
- ❖ RED: Hidden source causing prolonged exposure without dispersal.
- ❖ Nuclear weapon/IND: True fission explosion, catastrophic destruction.
- ❖ Response & Management: Involves detection, containment, medical triage, decontamination, crowd/media control, forensic evidence collection, and phased recovery (immediate, intermediate, long-term).

## References (Adapted from)

- AERB. Safety Guidelines for Radioactive Materials. [www.aerb.gov.in](http://www.aerb.gov.in)
- AERB, Guidelines on Security of Radioactive Sources
- BARC, Nuclear Emergency Preparedness and Response Guidelines
- AERB, Disaster Management Framework for Nuclear and Radiological Emergencies
- IAEA (2011) Nuclear Security Series No. 15 – Use of Radiation Detection Equipment for the Detection of Nuclear and Other Radioactive Material out of Regulatory Control
- IAEA (2004) Code of Conduct on the Safety and Security of Radioactive Sources ([https://www-pub.iaea.org/MTCD/Publications/PDF/Code-2004\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/Code-2004_web.pdf))
- IAEA (2002). Generic procedures for medical response during a radiological emergency (IAEA-TECDOC Series) [[https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-MEDICAL-2005\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-MEDICAL-2005_web.pdf)]

- IAEA (2015). Preparedness and response for a nuclear or radiological emergency (IAEA Safety Standards Series No. GSR Part 7)
- IAEA (2006) Manual for first responders to a radiological emergency.
- IAEA Responding to a radiological or nuclear terrorism incident: a guide for decision makers, NCRP report no.165
- WHO. (2017). Guidelines on Radiological Emergency Preparedness and Response.
- WHO (2005). Emergency medical preparedness and response
- WHO (2006) Manual for First Responders to a Radiological Emergency
- WHO (2017) Public Health Response to Radiological and Nuclear Emergencies
- EPA –United States Environmental Protection Agency  
(<https://iwaste.epa.gov/guidance/radiological-nuclear/rdd>)
- Second European IRPA Congress on Radiation Protection Paris, May 15 -19, 2006.  
(<https://www.osti.gov/etdeweb/servlets/purl/20854828>)
- UNSCEAR. (2000). Sources and Effects of Ionizing Radiation.
- REMM (U.S. Department of Health and Human Services) (2008). Planning Guidance for Response to a Dirty Bomb Attack.
- IAEA 2003 Reducing the threat of RDDs  
(<https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull45-1/45102091216.pdf>)
- National Council on Radiation Protection and Measurements(NCRP) (2008). Management of persons contaminated with radionuclides: Handbook (NCRP Report No. 161). Bethesda, MD: NCRP.
- NCRP. (2021). Medical Response to Radiological Emergencies

### **Suggested Reading**

- REMM (U.S. Department of Health and Human Services) (2008). Planning Guidance for Response to a Dirty Bomb Attack.

- IAEA (2004) Code of Conduct on the Safety and Security of Radioactive Sources ([https://www-pub.iaea.org/MTCD/Publications/PDF/Code-2004\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/Code-2004_web.pdf))

### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand the effects of radiation exposure
- Identify key epidemiological evidence from major radiation exposure incidents.

## Chapter 9

### Long Term Effects of Radiation

#### 1. Introduction

Long-term effects of ionizing radiation are delayed health consequences that may appear months to years after exposure. These effects are primarily stochastic in nature, meaning they occur by chance and the probability increases with dose, but severity is independent of dose.

#### 2. Effects of Radiation Exposure

- ❖ Radiation exposure can lead to a range of biological effects, depending on the radiation type, dose, duration, and route of exposure. Understanding these effects is crucial for risk assessment, medical management, and the formulation of radiation protection guidelines.
- ❖ Our knowledge of radiation effects comes from major evidence streams:
  - Human epidemiological studies
  - Animal and plant studies (experimental radiobiology)
  - Cellular and molecular biology research
- ❖ The integration of findings from these fields offers a comprehensive understanding of how ionizing radiation interacts with and impacts biological systems.

## 2.1. Epidemiological Studies in Humans

- ❖ Human studies provide real-world data on radiation effects, based on observations of exposed populations. Key sources include:
  - Atomic Bomb Survivors (Hiroshima and Nagasaki): Provided foundational data on dose-response relationships, showing increased risks of leukemia, solid cancers, and cataracts.
  - Chernobyl and Fukushima Accidents: Studies have reported an increased incidence of thyroid cancers among children exposed to radioactive iodine, and potential mental health effects due to evacuation and radio phobia.
  - Occupational and Medical Exposure: Workers in nuclear facilities, radiologists, and patients receiving repeated scans or radiotherapy offer insights into chronic low-dose effects and accidental overexposure.
  - Radiation Therapy Patients: Clinical cases reveal tissue-specific effects, secondary malignancies, and late tissue injury patterns.
- ❖ Strengths: Direct relevance to humans, long-term follow-up data.
- ❖ Limitations: Variability in exposure dose estimates, confounding factors (e.g., lifestyle, environment)

## 2.2 Experimental Radiobiology (Animal and Plant Studies)

- ❖ Controlled studies using animals and plants allow scientists to:
  - Define dose thresholds for different effects (e.g., sterility, organ damage, carcinogenesis).
  - Understand mechanisms of radiation injury such as apoptosis, fibrosis, or immune suppression.
  - Evaluate effects of fractionated doses, dose rate, and radiation quality ( $\alpha$ ,  $\beta$ ,  $\gamma$ , neutron).
  - Test radio protective agents and treatments in experimental models.
- ❖ Examples:
  - Mice and rats used to study radiation-induced cancer and organ-specific damage.
  - Plants like Arabidopsis used to study DNA repair and mutation.
- ❖ Advantages: Controlled variables, reproducibility, mechanistic insights.
- ❖ Disadvantages: Limited extrapolation to humans due to species differences.

### 2.3 Cellular and Molecular Biology Research

- ❖ At the molecular level, ionizing radiation affects cells by:
  - Ionizing water molecules leading to the formation of free radicals (e.g., hydroxyl radical).
  - Damaging DNA, causing single- and double-strand breaks, mutations, or chromosomal aberrations.
  - Inducing apoptosis, mitotic arrest, or senescence in sensitive cells.
  - Affecting cell signaling pathways (e.g., p53, ATM/ATR) that regulate repair and survival.
  - Modifying gene expression and potentially triggering epigenetic changes.
- ❖ Techniques such as  $\gamma$ -H2AX foci staining, micronucleus assays, and comet assays help quantify damage and repair.
- ❖ Importance: Explains how microscopic damage leads to macroscopic health effects, supports risk models, and underpins radiological protection standards.

**2.4 Integration of Evidence:** No single approach provides a full picture. It is the triangulation of evidence—from human data, experimental models, and cellular/molecular studies—that enables:

- Risk modelling (e.g., Linear No-Threshold Model)
- Understanding stochastic vs. deterministic effects
- Designing effective radiation protection policies
- Developing diagnostics and therapies for radiation exposure

### 3. Case Studies and Epidemiological Findings

Understanding the long-term effects of ionizing radiation requires evidence from both accidental and occupational exposures, as well as natural background exposure. The common sources of data on stochastic health effects are:

- Early radiologist and medical physicists
- Radium-dial painters

- Uranium-miners, nuclear industry workers
- Atomic bomb survivors and their future generations
- Overexposed from accidents
- Irradiated for medical reasons

The following case studies provide critical insights into radiation-induced health outcomes, particularly cancer, genetic effects, and non-cancer illnesses.

#### 4. Case study: Japanese Atomic Bomb Hiroshima and Nagasaki Survivors (Japan, 1945 – ongoing Life Span Study)

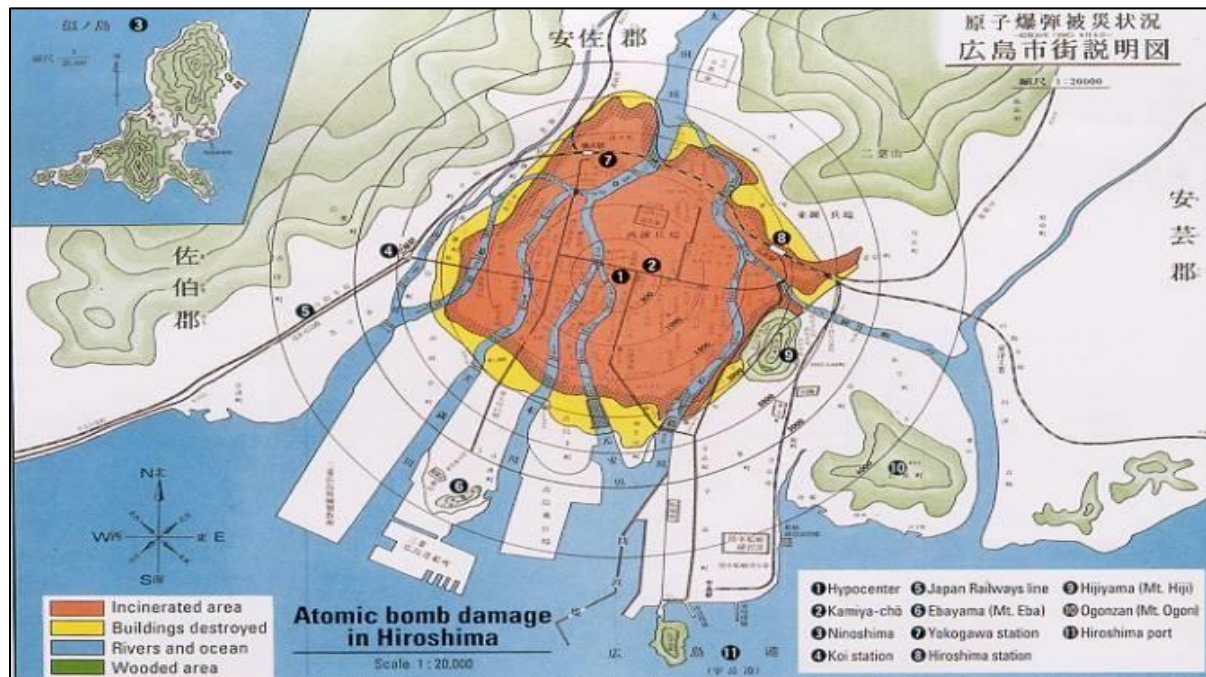


Fig.no. 9.1 –Atomic Bomb damage in Hiroshima and Nagasaki

##### 4.1 Background

- The Life Span Study (LSS) is the most comprehensive and long-running epidemiological study on the health effects of ionizing radiation exposure in humans. It involves survivors of the atomic bombings of Hiroshima and Nagasaki in August 1945, exposed to high doses of gamma and neutron radiation.

- In 1947, Atomic Bomb Casualty Commission (ABCC) was established by the U.S. National Academy of Sciences to study the survivors of Hiroshima and Nagasaki. Initial studies began, including data collection and health surveys.
- Initiated in 1950 and conducted jointly by the Radiation Effects Research Foundation (RERF), it follows approximately 120,000 individuals, including about 86,572 survivors with individual radiation dose estimates and 26,580 non-exposed controls. The cohort has been studied for mortality, cancer incidence, non-cancer diseases, genetic effects, and trans generational outcomes, making it the global benchmark for radiation risk assessment.

#### 4.2 Cohort and Methodology

- Study Population Total: **~120,000 individuals** (Both sexes, across all age groups)
- Groups included:
- **Exposed survivors** – **~94,000** persons who were in Hiroshima or Nagasaki at the time of bombing.
- **Non-exposed comparison group** – **~27,000** persons who were not in the cities during the bombings (controls).
- Follow-up: From 1950 to present (mortality, cancer incidence, health outcomes).
- Data Sources: Population registries, health surveys, death certificates, cancer registries.
- Study design → prospective, long-term observation.

#### 4.3 Radiation Exposure Classification

Distance from Hypocenter	Estimated Radiation Dose (Sieverts, Sv)
<1 km	High dose (>1 Sv)
1–2 km	Moderate (0.1–1 Sv)
>2.5 km	Very low or negligible dose

Table no. 9.1- Radiation Exposure Classification

#### 4.4 Cancer Incidence and Mortality

- Risk is dose-dependent and follows a linear no-threshold (LNT) model.
- 2020 LSS report showed:
  - 10,929 solid cancer deaths in survivors
  - ~1,000 were attributable to radiation
- Solid cancer:
  - Risk appears decades after exposure, persisting for the survivors’ lifetimes.
  - Those exposed at younger ages carry the highest lifetime risk.
  - By the most recent follow-ups, ~25% of excess solid cancer deaths occurred in just the past 5 years of study

Cancer type	Risk Increase ( <u>per 1 Sv exposure</u> )
Leukemia (sharp increase)	5–10x increase, especially in first 10 years post bombing
Solid cancer	1.5x increased risk overall
Breast, lung, stomach, colon, thyroid	Significantly elevated risks

Table no. 9.2- Cancer Incidence

#### 4.5 Life Expectancy - Reduced by ~1.3 years per 1 Sv

- For lower doses (<100 mSv), impact is not statistically significant
- Most survivors lived normal life spans unless exposed to high radiation
- Radiation didn’t cause rapid death except for those very close to the blast (which is outside the LSS cohort, as they did not survive long enough for follow-up).

#### 5.1.6 Non-Cancer Diseases - Slight increase at high doses

Non-Cancer Diseases	Risk Pattern
Cardiovascular disease	Slight dose-dependent increase
Cerebrovascular disease (stroke)	Increased risk at higher doses

Respiratory disease	Minor risk elevation
Cataracts	Strong association (at doses >500mSv)

Table no. 9.3-Risk Pattern observed in Non-cancer diseases

**4.7 Genetic Effects on Offspring:** No detectable heritable effects in children of survivors. Studies of 70,000 offspring of the atomic bomb survivors have failed to identify an increase in congenital anomalies, cancer, chromosome aberrations.

**4.8 Psychological and Social Impact:** While the 2020 RERF report emphasizes epidemiological, clinical, and molecular findings, it notes that psychological impacts (e.g., stigma, social effects) continue to be part of ongoing research, often integrated via the Adult Health Study (clinical arm of the LSS)

**4.9 Public Health & Policy Impact:**

- Data from the LSS directly inform ICRP radiation protection guidelines, UNSCEAR risk models, and US NRC/DOE standards.
- Reinforced the Linear No-Threshold (LNT) model as the global standard for radiation safety.
- Emphasized the importance of lifelong monitoring for radiation-exposed populations.

**The studies showed that solid cancer risk increases linearly with dose, with no threshold observed. Leukemia risk is elevated even at lower doses with shorter latency. Non-cancer diseases, including cardiovascular disease, are also associated with radiation at moderate to high doses. No confirmed increase in hereditary effects among children of survivors, but follow-up continues. Radiation effects are greater in those exposed at younger ages, especially in children and fetuses.**

## 5. Case Study: Natural Background Radiation Exposure in HLNRA of Kerala, India

### 5.1 Introduction

- **High-Level Natural Radiation Areas (HLNRAs)** are regions where background radiation levels are significantly higher than the global average due to natural sources like radioactive minerals in soil and rocks.

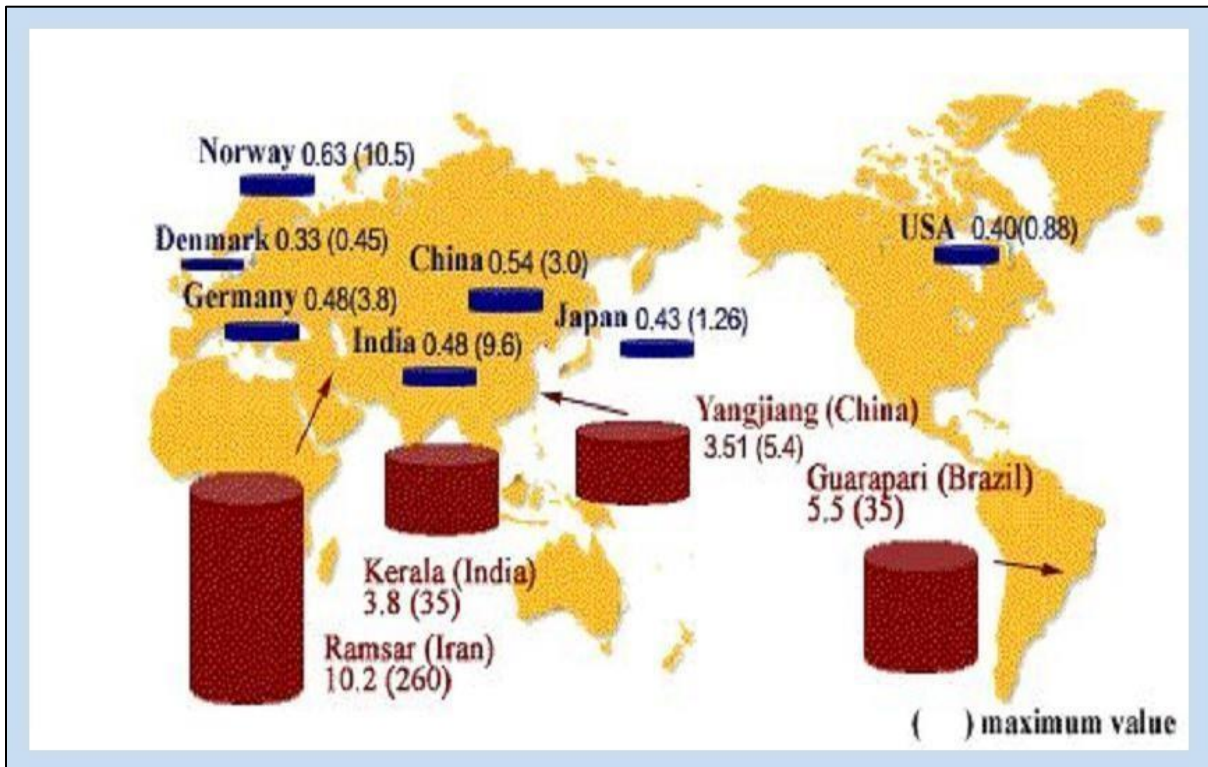


Fig.no. 9.2- High Level Natural Radiation Areas (HLNRA)

The figure 9.2 shows the level of background radiation compared to other areas in the world which are known to have high levels of natural radioactivity. It also illustrates the background radiation levels in some countries. The numbers listed represent the average annual dose rate (in mSv). Numbers in parentheses indicate the maximum annual dose rate.

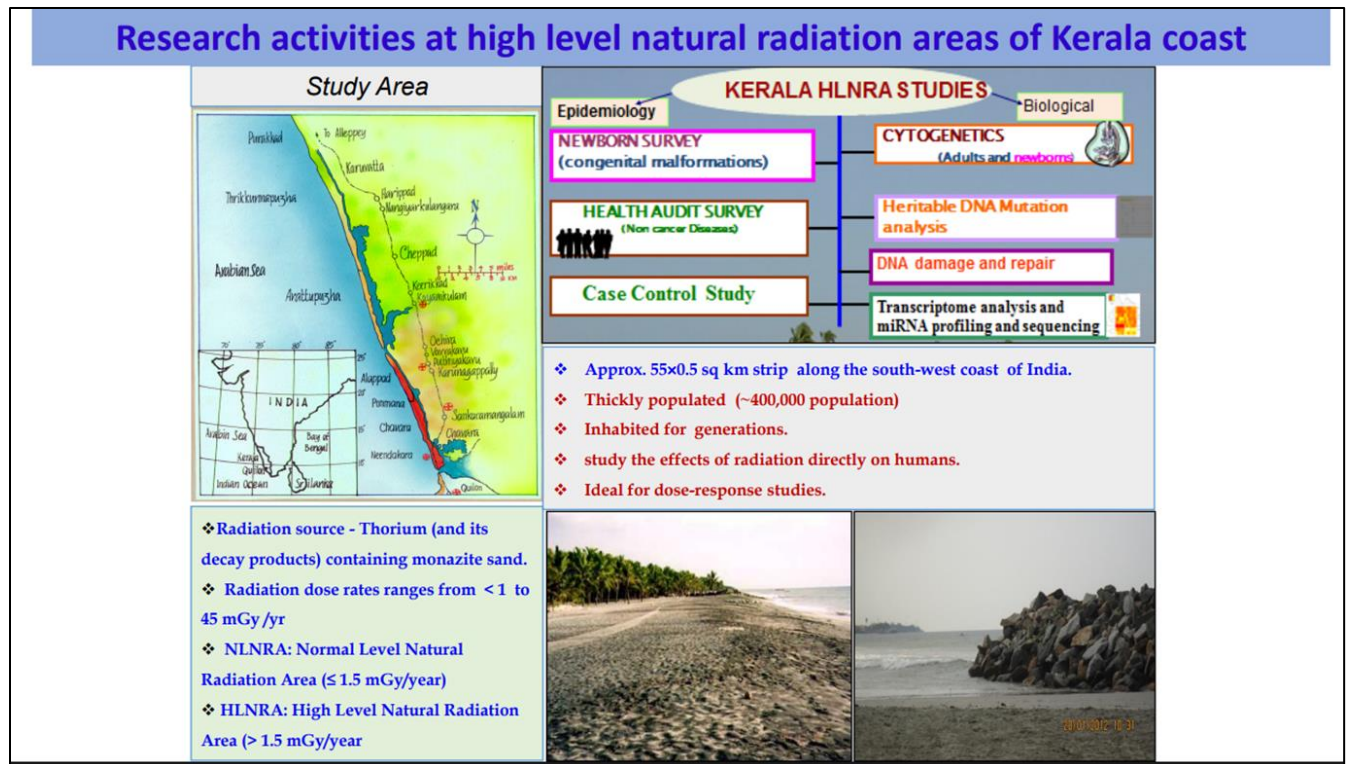


Fig.no. 9.3- High Level Natural Radiation Areas of Kerala Coast

- Background: The coastal region of Karunagappally in Kerala, India, is known for its high natural background radiation due to monazite-rich beach sands containing thorium. This region, termed a High Level Natural Radiation Area (HLNRA), offers a unique setting to study the long-term effects of chronic low-dose radiation exposure in a human population.

### 5.2 Research Initiation and Support:

- The study was initiated in 1990 by the Regional Cancer Centre (RCC), Trivandrum.
- It received technical advice on dosimetry from the Bhabha Atomic Research Centre (BARC).
- Funding came from the Department of Atomic Energy (DAE), Government of India.
- Since 1999, the Health Research Foundation, Japan has supported parts of the study.
- The project forms part of India's second Rural Cancer Registry.

### 5.3 Study Design:

- Population: Over 4,00,000 residents in HLNRA and nearby control areas, including all age groups and both sexes.

- Dosimetry: Precise individual dose estimation based on residence location, duration, and external/internal exposure.
- Cancer Monitoring: Continuous surveillance for cancer incidence, with a focus on leukemia and solid tumors.

#### **5.4 Findings:**

- No Observed Increase in Cancer Risk: Despite significantly higher radiation levels (up to 5–15 mGy/year, compared to the global average of ~2.4 mGy/year), no statistically significant increase in overall cancer incidence was found among residents of HLNRA.
- High level natural background radiation did not have any significant effect on the frequency of congenital malformations, down syndrome and still births.
- No significant difference was observed in the frequency of chromosomal aberrations, micronuclei, telomere length in newborns and adults.
- DNA damage (comet assay and H2AX foci) showed a decrease in the high dose group of HLNRA.
- Molecular studies indicated no increase in mutation rate.

#### **5.5 Consistency with International Evidence:**

- The study supports the conclusion that current international estimates of cancer risk at low doses (e.g., from ICRP, UNSCEAR) are not substantially underestimated.
- Scientific and Public Health Implications
  - Low-dose Risk Models Validated: The Kerala HLNRA data offer reassurance that chronic low-dose exposure does not lead to measurable increases in cancer risk under current radiation protection standards.
- Natural Laboratories for Radiation Biology: HLNRA Kerala serves as a valuable natural laboratory complementing other major epidemiological data sets such as the Life Span Study (LSS) of Hiroshima-Nagasaki survivors.

- Policy and Communication Relevance: These findings can help in public reassurance and evidence-based policymaking regarding low-level radiation exposure from natural sources, medical imaging, or nuclear industry operations.

### Take Home Message:

- ❖ Radiation exposure can lead to a range of biological effects, depending on the type, dose, duration, and route of exposure. Investigation of radiation effects on humans, especially late health effects has been based on past experiences.
- ❖ The LSS confirms that ionizing radiation increases cancer risk in a dose-dependent manner, with no safe threshold.
- ❖ Effects are long-lasting, persisting for over seven decades' post-exposure.
- ❖ Studies of 70,000 offspring of the atomic bomb survivors have failed to identify an increase in congenital anomalies, cancer, chromosome aberrations.
- ❖ High Level Natural Radiation Area (HLNRA), offers a unique setting to study the long-term effects of chronic low-dose radiation exposure in a human population

### References (Adapted from)

- IAEA. (2012). Radiation Biology: A Handbook for Teachers and Students.
- WHO. (2013). Health Risk Assessment from the Nuclear Accident after the 2011 Great East Japan Earthquake and Tsunami.
- UNSCEAR. (2020). Sources, Effects and Risks of Ionizing Radiation: Report to the General Assembly.
- Hall, E.J., & Giaccia, A.J. (2019). Radiobiology for the Radiologist (8th ed.).
- ICRP Publication 103. (2007). The 2007 Recommendations of the International Commission on Radiological Protection.
- Rowland RE (1994), Radium in Humans, Argonne National Laboratory
- IAEA. (1999). Occupational Radiation Protection.

- Radiation Effects Research Foundation (RERF). Life Span Study Report 2020.
- BARC & ICMR Studies – HLNRA. Kerala
- Nair RR et al. (2009), Epidemiological Study of Health Effects from High Natural Background Radiation, BARC
- Regional Cancer Centre, Trivandrum (1990 – ongoing)
- Health Research Foundation, Japan (since 1999)
- UNSCEAR 2000 & 2008 Reports
- ICRP Publication 103 (2007)
- Images:
  1. Fig.no. 9.1 (<https://www.globalsecurity.org/wmd/ops/images/hiroshima-117.jpg>)
  2. Fig.no. 9.2 (Natural Background Radiations, Radioadaptive Response and Radiation Hormesis, Sajad Borzouei-Sileh et al.)
  3. Fig.no. 9.3 (BARC - [https://www.barc.gov.in/group/66\\_h225\\_324.pdf](https://www.barc.gov.in/group/66_h225_324.pdf))

### **Suggested Reading**

- Radiation Effects Research Foundation (RERF). Life Span Study Report 2020.
- Nair RR et al. (2009), Epidemiological Study of Health Effects from High Natural Background Radiation, BARC

## Chapter 11

### Topic: Medical Management of External Contamination

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand types of Contamination
- Preparedness for assessment, evaluation and medical management of externally contaminated patients and treatment

#### 1. Introduction

Understanding the types and pathways of radionuclide contamination is essential to managing radiological safety in nuclear, medical, and industrial contexts.

#### 2. Radionuclide Contamination and its type

Radionuclide Contamination is the presence of radioactive substances (radionuclides) on or in a material or the human body, where the concentration exceeds specified limits set by the competent authority. (AERB)

This contamination can occur in various locations, including air, water, and in unwanted places/surfaces (including human body) in amounts that may be harmful to health and safety of personnel and the surrounding environment.

Radioactive contamination is classified into two main types: **external and internal**

**2.1 External contamination** refers to the presence/deposition of radioactive material on the surface of the body, clothing, or other objects. It does not indicate that radioactive substances have entered the body, but it can still result in external radiation exposure and poses a risk of

spreading contamination to others or the environment. If not promptly removed, external contaminants can also become a source of internal contamination through inhalation, ingestion, or absorption.

Detection is usually carried out using survey meters such as Geiger–Müller counters, alpha/beta probes, or other contamination monitors. Most of the external contamination can be effectively removed by simple measures such as changing clothes, washing the skin with soap and water, or cleaning affected surfaces.

External contamination may occur in various scenarios, including nuclear power plant accidents like Chernobyl or Fukushima, radiological dispersal device (“dirty bomb”) events, mismanagement of medical or industrial radioactive sources, transportation accidents involving radioactive materials, or laboratory spills and equipment failures.

**2.2 Internal contamination** occurs when radioactive substances enter the human body through inhalation, ingestion, absorption via the skin or wounds, or by injection. Once inside, these radionuclides can irradiate tissues and organs from within, leading to internal exposure from alpha, beta, or gamma emissions. The pathways of entry include inhalation of contaminated air, ingestion of contaminated food or water, absorption through intact or broken skin, and direct contamination of wounds.

Detection of internal contamination is typically carried out using bioassays, urinalysis, or whole-body counting techniques.

Management depends on the specific radionuclide involved and may involve the use of decorporation agents such as DTPA, administration of potassium iodide, or supportive medical care to limit absorption and promote elimination from the body.

Differentiating points	External contamination	Internal Contamination
Detection	Easy to identify, usually with contamination monitors (like Geiger–Müller counters, alpha/beta probes etc.)	Difficult to identify, need specific techniques to quantify. <b>Pathways</b> for Internal Contamination are - Inhalation, Ingestion, Injection and absorption
Treatment/ Decontamination Procedure	Comparatively easy methods of decontamination.	Decontamination procedures (De-corporation) are not easy, often requires medical attention
Dose Reduction	External radiation dose (Exposure) can be minimized by <ul style="list-style-type: none"> <li>•Time</li> <li>•Distance</li> <li>•Shielding</li> </ul>	Internal dose depends on the half-life of radionuclide and the rate of elimination from the body.

Table no. 11.1—Types of Contamination

### 3. Sites of Accidents

- ❖ Radioactive materials used in industrial, medical, and research settings can lead to both internal and external contamination following an accident. In such situations, the potential hazard from internal exposure and the need for prompt medical intervention are especially critical.
- ❖ External or internal contamination may occur in several scenarios, including:
  - Reactor accidents involving core damage, resulting in inhalation, ingestion, or skin contamination with a mixture of fission products—most commonly cesium and iodine isotopes.

- Violations of safety regulations or operational procedures during handling, processing, or storage of radioactive materials.
- Incidents involving damaged or leaking sealed sources, such as those containing Iridium-192, Cesium-137, Cobalt-60, or Radium-226.
- Therapeutic or diagnostic mishaps, including errors in radionuclide dose preparation or administration.
- Accidents during nuclear fuel fabrication, reprocessing, waste transportation, or disposal, which may lead to significant contamination and exposure risks.

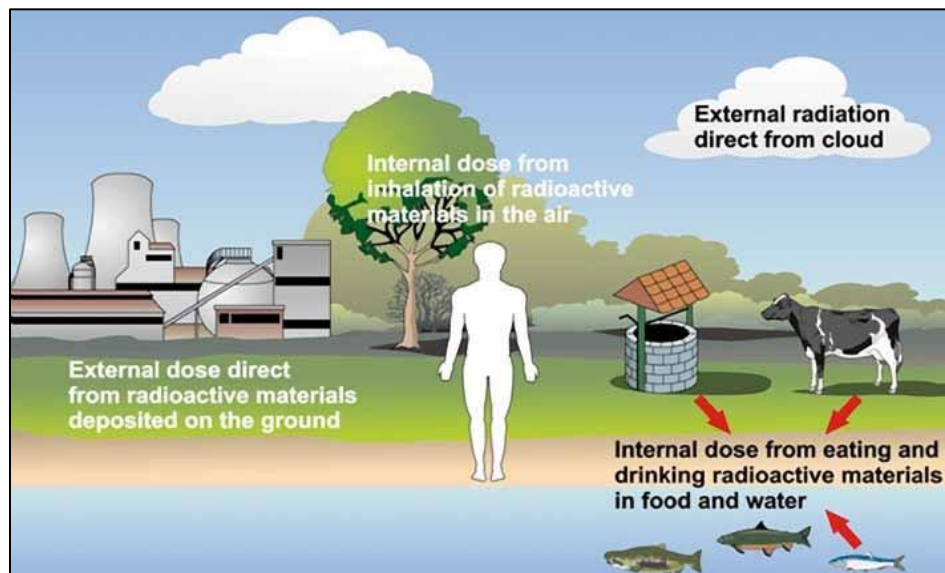


Fig. no. 11.1- Exposure pathways to humans from environmental releases of radioactive material

#### 4. Decontamination

Decontamination is the process of removing or reducing radioactive, chemical, or biological contaminants from persons, equipment, structures, or the environment, to prevent the spread of contamination and reduce radiation exposure to acceptable levels.

**Removal of radioactive material from the skin, hair, clothing, and surfaces is external decontamination.**

**Note:** This Chapter will cover External Decontamination in detail. Internal Decontamination and its Medical Management will be taken up in Chapter 12.

## 5. Presentation with External Contamination

- ❖ During radiological accidents, victims may present with contamination on the skin or within wounds, and the pattern of contamination determines the urgency and method of management. External contamination does not imply internal uptake, but if not managed promptly, it can spread to wounds, mucous membranes, healthcare workers, and the environment.
- ❖ Victims may present in several ways:
  - **Contaminated Intact Skin (no injury)**: This is the most frequent presentation, in which radioactive particles settle on the skin, hair, or clothing without causing any visible injury. The primary concern is external exposure, as the risk of internal absorption remains low when the skin barrier is intact.
  - **Contaminated Wounds (open injuries)**: Open cuts, abrasions, puncture wounds, and lacerations contaminated with radioactive material carry a significantly higher risk because radionuclides—especially insoluble particles—can enter the body directly and deposit in local tissues.
  - **Burns with Radioactive Material Embedded**: Burn injuries create damaged tissue that can trap radioactive particles, allowing them to adhere tightly or lodge within necrotic layers. This increases the potential for absorption through compromised/ injured skin, and contamination may persist even after routine washing.
  - **Combined Injuries (radiation and trauma/thermal injury)**: In some cases, patients may suffer conventional trauma—such as fractures, crush injuries, or burns—alongside external contamination or significant radiation exposure. These combined injuries increase the overall severity and complicate management, as radiation effects can worsen healing and elevate infection risk.
- ❖ Different presentations of external contamination require tailored assessment and decontamination strategies.

## 6. First Aid

- ❖ First aid for individuals contaminated with radioactive material should begin with stabilization of the patient, following the standard ABCs—Airway, Breathing, and Circulation—before addressing contamination. Contaminated clothing should be carefully removed, as this simple measure can eliminate up to 90% of external contamination. Any open or contaminated wounds should be covered with waterproof dressings to prevent radionuclide uptake. It is equally important to protect medical personnel during decontamination; responders should wear appropriate Personal Protective Equipment (PPE), including gloves, gowns, masks or respirators, and dosimeters, to prevent self-contamination while providing care.

- **Stabilization (ABCs)**
- **Remove contaminated clothing**
- **Cover open wounds**
- **Protect responders**

Box 11.1 -First aid for contaminated individuals

## 7. Order of Priority in Management

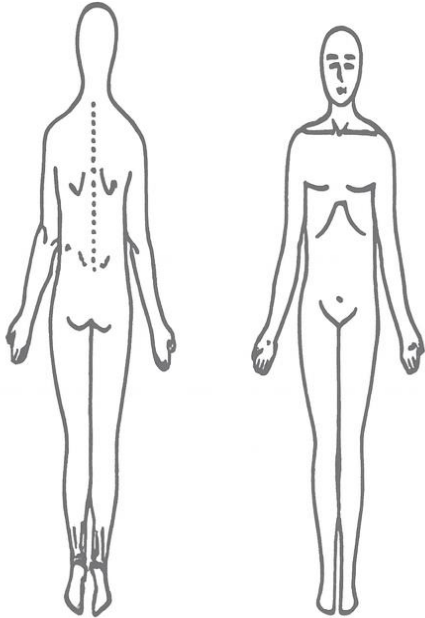
- ❖ According to IAEA and BARC guidelines, the management of radiological casualties—whether individual cases or mass-casualty events—must follow a clear hierarchy to ensure both medical safety and radiation protection.
- ❖ **Life-threatening conditions take absolute priority over decontamination:** Interventions for airway obstruction, severe hemorrhage, shock, or cardiorespiratory arrest must never be delayed to address contamination. Immediate lifesaving care always comes first.
- ❖ **Stabilize the patient using the ABCs (Airway, Breathing, Circulation):** Once immediate threats are controlled, follow the standard trauma-care sequence. Securing the airway, ensuring adequate ventilation, and maintaining circulation form the foundation of initial management before handling contamination.

- ❖ **Prevent the spread of contamination (isolate the patient and use protective barriers):** Place the patient in a designated controlled area—a space marked and restricted to limit the movement of radioactive material. Use protective sheets, absorbent pads, gloves, PPE, and disposable coverings to prevent contamination of surfaces and staff.
- ❖ **Survey and assess the contamination level:** Use appropriate detection instruments—such as Geiger-Müller counters, scintillation probes, or contamination monitors—to determine the presence, extent, and location of radioactive material on the patient’s body or clothing.
- ❖ **Decontaminate before detailed treatment, if it does not compromise safety:** Once the patient is stable, perform external decontamination measures such as removing clothing and washing the skin. This should occur before more detailed diagnostic or therapeutic procedures, provided the process does not interfere with essential medical care.

## 8. Assessment of external contamination

- ❖ External contamination should be assessed using appropriate radiation detection instruments, such as Geiger-Müller (GM) counters or alpha/beta probes. Pancake-type probes are preferred for scanning large surface areas efficiently. The procedure involves conducting a systematic head-to-toe survey of the patient, documenting the location, type, and intensity of contamination. Surveys should be repeated after each decontamination step to evaluate effectiveness, and all findings must be recorded for both medical follow-up and regulatory reporting.
- ❖ In addition to instrument-based measurements, relevant clinical and exposure information should be obtained to guide management. This includes details of the accident, including date and time if known, the type of radiation involved, and the likelihood of whole-body exposure or associated symptoms such as anorexia, nausea, vomiting, or diarrhea. The possibility of contamination by radioactive dust or liquids, as well as any history of transient erythema, and the presence of fixed erythema, epilation, edema, or burns should also be documented. This comprehensive assessment ensures appropriate treatment and monitoring for both immediate and delayed radiation effects. (Figure 11.2)

**2.C Front and Back view of the Identity Tag used in the First-Aid-Post.**

<p style="text-align: center;"><u>IDENTITY TAG</u> (FIRST AID POST)</p> <p>NAME: : _____</p> <p>DEPT:            DIVN. _____</p> <p>CONTAMINATION            : Y/N</p> <p>SITE OF CONTAMINATION : _____</p> <p>INJURY                        : Y/N</p> <p>SITE OF INJURY            : _____</p> <p>OVER EXPOSURE            : Y/N</p> <p>NAUSEA: Y/N, VOMITING : Y/N</p> <p><u>PRELIMINARY ACTIONS TAKEN:</u></p> <p>TREATMENT                :</p> <p>FIRST AID                 :</p> <p>DECONTAMINATION:</p> <p>TO: PERSONNEL DECONTAMINATION CENTRE / SITE HOSPITAL</p>	<div style="text-align: center;">  <p><u>POSTERIOR</u>            <u>ANTERIOR</u></p> <p>(MARK THE LOCATIONS OF CONTAMINATION / INJURY)</p> </div>
--	---

POSTERIOR

ANTERIOR

Fig.no. 11.2- Information to be obtained for medical management of patient with external contamination

### 8.1 External Decontamination Procedure

- ❖ External decontamination begins by **delineating the contaminated area** and establishing controlled zones—hot, warm, and cold—to prevent the spread of radioactive material.

- ❖ **Body orifices**, including the mouth, nose, ears, and eyes, should be cleaned first using dry wipes, cotton, or paper towels, with initial swabs preserved for radio-assay. Specific measures include brushing teeth and frequent rinsing of the oral cavity, gargling the pharyngeal region with 3% hydrogen peroxide, rinsing the nose with tap water or physiological saline, flushing eyes from the inner to the outer canthus, and rinsing the external ear using a syringe with water.
- ❖ Radiation survey instruments such as Geiger-Müller counters or pancake probes should be used to **monitor contamination levels** throughout the procedure, including checking for radioactive shrapnel that may require surgical removal under appropriate safety precautions.
- ❖ Decontamination should follow a prioritized order: **wounds first, followed by orifices, and then intact skin, proceeding from head to feet to prevent downward spread and from the periphery to the center to avoid contaminating clean areas.**
- ❖ **Initial dry wiping removes loose contamination from intact skin and around wounds**, which should be isolated with waterproof dressings to prevent radionuclide absorption. **Wet wiping of all body surfaces** is then performed using **tepid water and mild soap**, applying inward or circular strokes to avoid spreading contamination while preserving the skin barrier.
- ❖ For wounds or abrasions, **controlled bleeding may be encouraged by occluding venous return**, and the severity of injury and contamination assessed. Punctures, lacerations, or embedded contaminants may require **surgical debridement or excision**, with care to preserve function and cosmetic appearance.
- ❖ Concurrent measures should **prevent systemic absorption, using normal saline or radionuclide-specific antidotes, and monitoring all washings, excised tissues, and instruments.**
- ❖ **Urine and feces should be examined to assess potential internal contamination.** Residual contamination may persist in scabs or epidermal layers, as the epidermis naturally renews over 12–13 days; therefore, surgical removal of unruptured skin is generally not recommended even if contamination persists above permissible levels.
- ❖ **Persistent contamination** should be addressed by **repeating monitoring and decontamination steps**, washing with soap/detergent, and, where applicable, using radionuclide-specific solutions—**1% Ca-DTPA for plutonium, potassium rhodizonate for**

strontium, sodium bicarbonate for uranium, and 1% Ca-DTPA or diluted HCl for fission products.

- ❖ Decontamination should continue until contamination levels are acceptable and the skin condition is satisfactory. If the skin is irritated or damaged, decontamination should be halted and the area covered with a sterile dressing until healing occurs.
- ❖ Finally, all details—including the type and location of contamination, monitoring results, and any special measures—should be **documented** before releasing the patient for further care. Persistent contamination in wounds or critical areas must be documented and reported for regulatory and medical management.

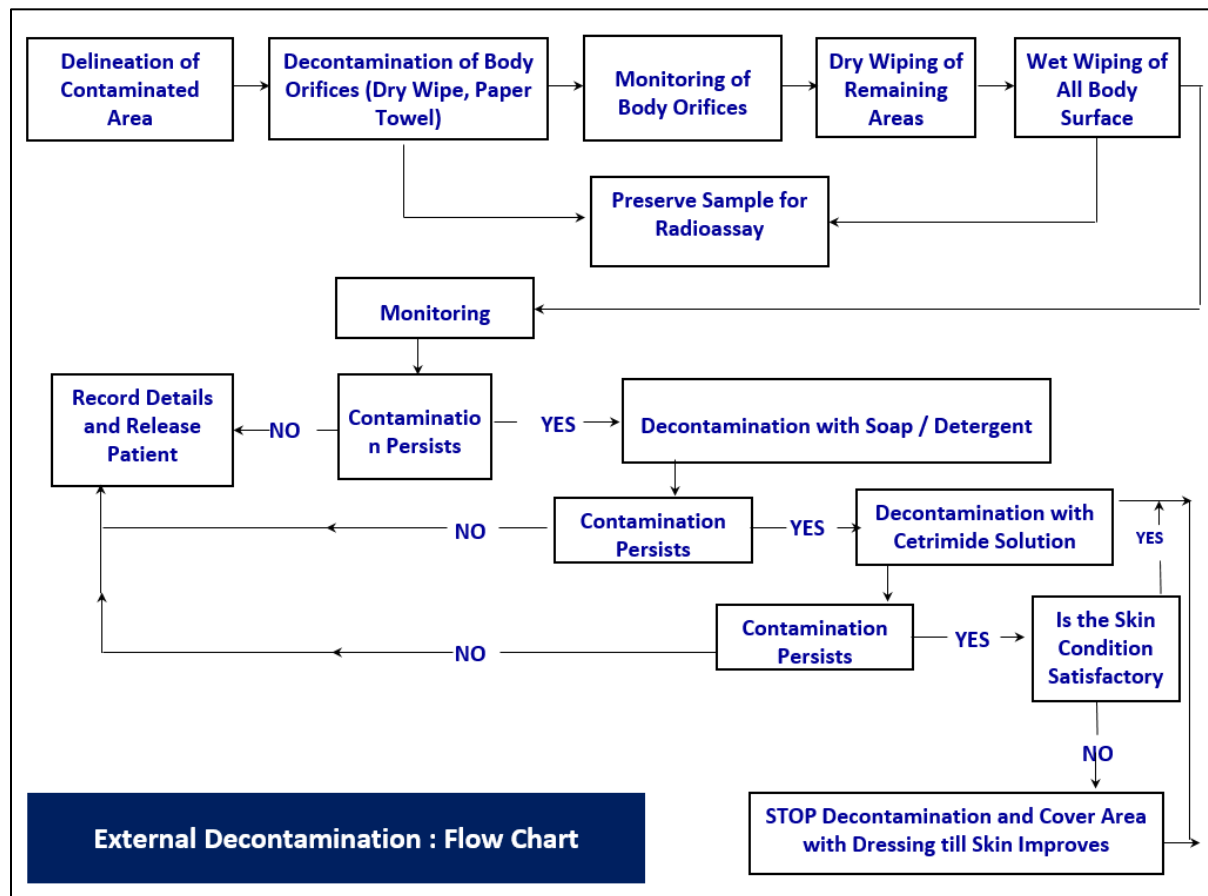


Fig.no.11.3 - Flow Chart of External Decontamination

## 8.2 Useful Therapeutic Agents for Skin Decontamination:

- ❖ **Common soap or detergent solution** (for skin and hair)- low acidity (pH -5) is recommended.

❖ **Chelating agents:**

- **Ethylene diamine tetra-acetic acid (EDTA) solution:** solution of EDTA 10% for skin or hair contaminations with transuranium, rare earth and transition metals
- **Diethylenetriamine penta-acetate (DTPA) solution:** DTPA 1% in aqueous acid solution (pH ~4) for washing skin after contamination by transuranic, lanthanides or metals (cobalt, iron, zinc, manganese).

**9. Protecting Medical Staff during Decontamination**

- ❖ **Use of Personal and Protective Equipment (PPE):** Medical staff should wear appropriate PPE such as gloves, gowns, impermeable aprons, face shields or goggles, masks/respirators, and shoe covers to avoid contact with radioactive contaminants.
- ❖ **Change gloves regularly:** Gloves must be replaced, especially after contact with contaminated areas or patients, to prevent cross-contamination.
- ❖ **Use of personal dosimeters:** All personnel involved in decontamination should wear personal dosimeters (e.g., thermoluminescent dosimeters or electronic dosimeters) to monitor cumulative radiation exposure in real-time as available and appropriate.
- ❖ **Full-body contamination survey:** Before leaving the controlled (decontamination) area, all medical staff must undergo a full-body contamination survey using suitable radiation detection instruments to confirm they are free from contamination.

**10. Assessing Effectiveness of Decontamination:**

- The physician will want to know when decontamination efforts can be stopped or when it is no longer possible to remove persistent contamination. Citing an absolute numerical value requires many assumptions and can be misleading. Radiological survey techniques alone can be misleading since the count rate increases as the probe is moved closer to the skin and decreases as it is moved away.
- Great care should be taken to hold the instrument probe at the same distance for re-monitoring. Other factors to be considered relate to where the residual contaminant is on the

skin. For example, is the contaminant in the superficial part of the cornified layer? Is it uniformly or non-uniformly distributed? Has it penetrated to the basal layer? These questions are not easily answered and medical judgement is advised.

- For all contaminants, the rate of absorption depends on the physical and chemical properties of the respective radionuclides. For residual contaminants on or near the skin surface, epithelial sloughing will be the primary mode for reducing contamination levels. The rate of sloughing is similar to the turnover time of the horny layer or about six to seven per cent per day.
- Thus, it is not realistic to establish arbitrary radiation levels that must be achieved during decontamination. Nevertheless, the contaminated individual usually desires to have as much contaminant removed as possible. The physician should be prepared to advise the patient regarding the balance or medical judgement between residual contamination and skin injury.

## **11. Management of Radioactive Waste**

**Radioactive waste is any material that contains or is contaminated with radionuclides at concentrations or activities above clearance levels and for which no further use is foreseen.**

Effective management of radioactive waste is essential to protect human health, safety, and the environment. For management of radioactive wastes in the public domain, during the management of nuclear and radiological emergencies involving presence of radioactive sources and radioactive contaminated items. The plan for management of radioactive waste (both solid and liquid) shall indicate methodology to classify, categorize and segregate the radioactive wastes.

### **11.1 Principles of Radioactive Waste Management**

According to AERB, the management of radioactive waste should follow these key principles:

- **Protection of Human Health and Environment:** Waste must be managed to avoid any unacceptable risk to present and future generations.
- **Minimization of Waste Generation:** Source reduction through design, operation, and decontamination techniques.

- **Safety Throughout Waste Lifecycle:** Safe handling, transport, storage, and disposal must be ensured.
- **Security and Safeguards:** Waste containing fissile or radioactive material must be protected against unauthorized access or diversion.
- **Siting and Environmental Considerations:** Facilities for waste disposal must be sited with due consideration to geology, hydrology, and potential environmental impact.

**11.2 Classification of Radioactive Waste:** Classification is the process of identifying radioactive wastes based on their **physical form, activity level, half-life, and potential hazard**. It ensures that each type of radioactive waste is managed appropriately, safely, and in compliance with regulatory guidelines (such as AERB).

- ❖ Physical form: Solid (e.g., contaminated gloves, clothing, lab ware), liquid (e.g., effluents, chemical solutions), and gaseous (e.g., radioactive gases released from processes).
- ❖ Activity level: The amount of radioactivity present, which determines handling, storage, and shielding requirements.
- ❖ Half-life: The time required for the radioactivity to reduce by half; short-lived radionuclides may require temporary storage until decay, whereas long-lived radionuclides require long-term containment.
- ❖ Potential hazard: The risk to human health or the environment, influencing safety measures, containment, and disposal methods.

### **11.3 Categorization of Radioactive Waste**

- ❖ Categorization refers to grouping radioactive wastes based on their level of radioactivity, half-life of radionuclides, and potential exposure risk.
- ❖ Common Categories:
  - **Very Low-Level Waste (VLLW):** Minimal hazard; often suitable for disposal with conventional waste after regulatory clearance.

- **Low-Level Waste (LLW):** Contains small amounts of long-lived radionuclides; requires near-surface engineered storage.
  - **Intermediate-Level Waste (ILW):** Higher radioactivity; may need shielding and engineered storage facilities.
  - **High-Level Waste (HLW):** Highly radioactive; requires cooling, shielding, and deep geological disposal.
- ❖ Categorization ensures that radioactive waste is managed with appropriate safety measures, optimized handling, and regulatory compliance with both national (AERB) and international (IAEA) standards.

#### 11.4 Segregation of Radioactive Waste

- ❖ Segregation is the physical separation of different types of waste at the point of generation. This can be based on activity level, half-life, physical form, or contamination type, such as organic versus inorganic or sharps versus non-sharps. Segregation minimizes cross-contamination, reduces handling risks, simplifies treatment and storage, and ensures compliance with regulatory limits for radiation exposure.

#### 11.5 Stages of Waste Management

The flowchart in figure 11.4 explains radioactive waste management practices in India, based on BARC guidelines:

- ❖ **Waste Characterization:** The first step in managing radioactive waste is to characterize it by determining its physical, chemical, and radiological properties. Proper characterization is essential for selecting safe handling, processing, and disposal methods.
- ❖ **Radioactive Waste:** All materials containing radioactive substances are classified as radioactive waste and enter the formal management system to ensure safe handling and environmental protection.
- **Pre-Treatment:** Pre-treatment involves activities such as segregation, volume reduction, decontamination, and collection, aimed at making the waste easier and safer to handle during subsequent treatment stages.

- **Treatment:** Treatment processes are designed to reduce the volume of waste, remove radionuclides, or alter its properties to facilitate safer disposal. Common methods include chemical precipitation, filtration, ion exchange, and incineration.
  - **Conditioning:** Conditioning involves immobilizing the treated waste in stable matrices, such as cement, bitumen, or glass, and packaging it in secure containers. This step ensures long-term stability, prevents leakage, and minimizes environmental impact.
- ❖ **Final Pathways of Waste:** The ultimate pathway of radioactive waste depends on its properties. Exempt waste contains radioactivity levels low enough that it requires no special regulation or processing. Some waste materials, particularly those containing valuable isotopes like uranium or plutonium, can be recovered for recycling and reuse. Waste that cannot be reused is disposed of in engineered facilities, with near-surface disposal employed for low- and intermediate-level waste and deep geological repositories used for high-level waste, ensuring long-term safety and containment.

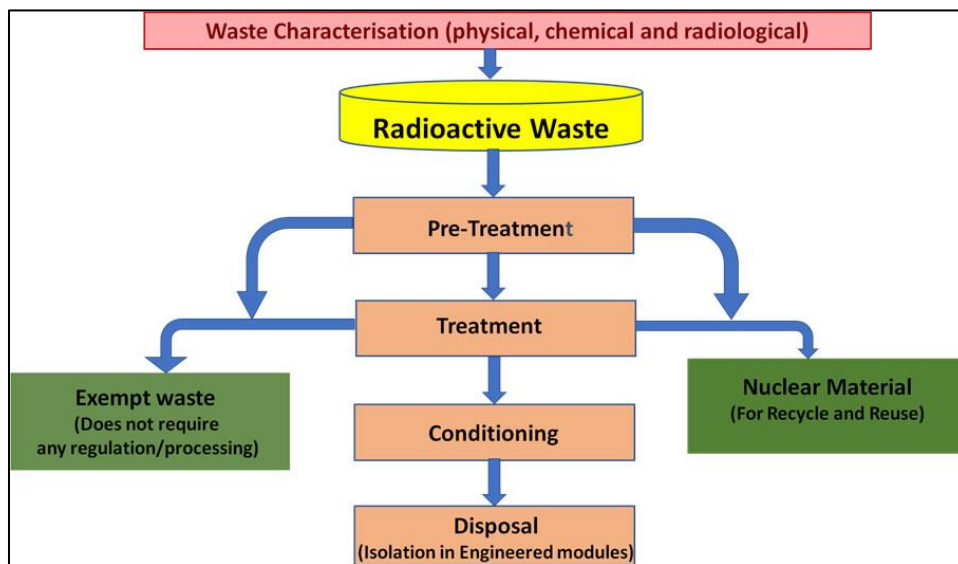


Fig.no. 11.4-- Stages of Radioactive Waste Management in India

Source: BARC

## 11.6 Types of Radioactive Waste:

- ❖ **Solid waste:** e.g., contaminated gloves, clothing, filters, tools.

- ❖ **Liquid waste:** e.g., laboratory effluents, cooling water, chemical solutions containing radioisotopes.
- ❖ **Gaseous waste:** e.g., radioactive gases released from processes (sometimes included under liquid/air handling systems).

#### **11.6.1 Solid Waste:**

- Solid radioactive wastes that are generated if buried in pits locally, then an exclusive burial ground for the solid radioactive waste should be located in an isolated area, which is duly fenced off.
- In India, disposal limits for ground burial of solid wastes have been specified by AERB

#### **11.6.2 Liquid Waste**

- In addition to the routes viz. urine and saliva, radioactivity is also excreted in sweat. As a result, the patients clothing, bed linen etc. get heavily contaminated and
- Such contaminated laundry should not be released for washing. It should be collected as radioactive waste and stored for decay up to i.e. almost 10 half-lives.
- After confirming by contamination monitoring that there is no radioactivity present, the clothing then can be released for washing.
- The liquid effluent generated should not be directly discharged into public sewerage system should be stored at least for the period of 10 half-lives for decay then only it can be discharged.
- Liquid effluent containing patient's urine from the isolation ward should be stored in the dedicated delay tank system and should not be directly discharged in into public
- Daily, monthly average concentration and annually discharge limits are specified in India by AERB

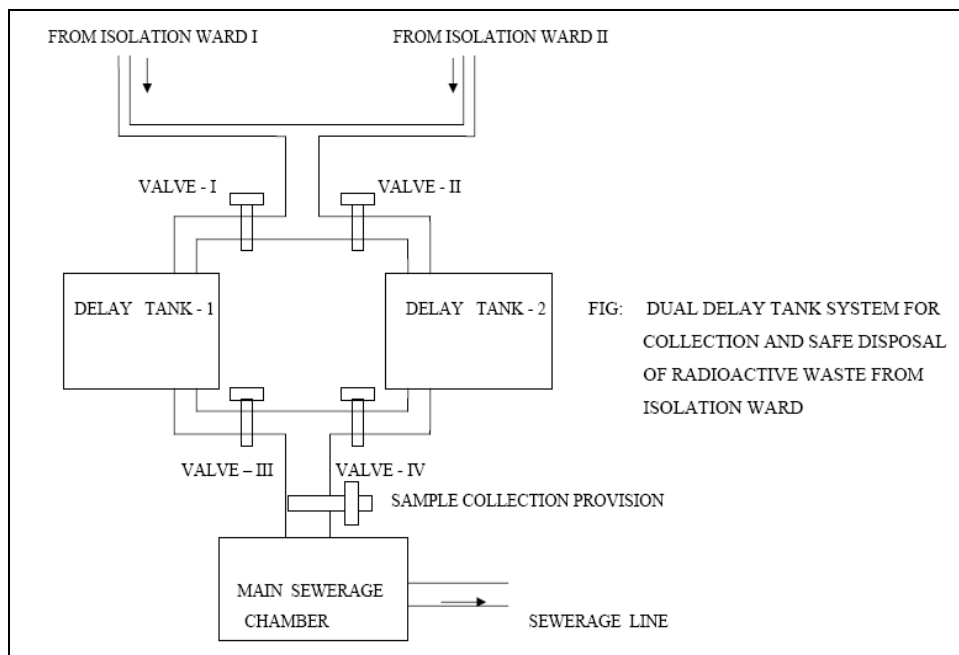


Fig.no. 11.5- Dual Delay Tank System for collection and safe disposal of Radioactive waste from Isolation ward.

### 11.6.3 Gaseous Waste:

- The vapors activity generated is exhausted through the fume hood and the radioactivity is trapped using an activated charcoal filter system.

### 11.7 Minor Spills Management

- Notify: Notify persons in the area that a spill has occurred
- Prevent The Spread: Cover the spill with absorbent paper
- Clean up: Use disposable gloves and remote handling tongs. Carefully fold the absorbent paper. Insert into a plastic bag and dispose of it in the radioactive waste container. Also insert all other contaminated materials such as disposable gloves into the plastic bag
- Survey: With a low-range, thin window G-M survey meter or an appropriate contamination monitor, check the area around the spill, hand, and clothing for contamination
- Report: Report incident to the radiation safety officer.

## 11.8 Major Spills Management

- **Call for help:** Notify the radiation safety office immediately
- **Clear the area:** Notify all persons not involved in the spill to vacate the room
- **Prevent the spread:** Cover the spill with absorbent material, but do not attempt to clean it up. Confine the movement of all personnel potentially contaminated to prevent the spread of contamination
- **Monitor:** Monitor all people involved in spill for contamination before leaving the room
- **Shield the source:** If possible, the spill should be shielded, but only if it can be done without further contamination and without significantly increasing your radiation exposure
- **Close the room:** Leave the room and lock the door to prevent entry.
- **Personnel Decontamination:** Contaminated clothing should be removed and stored for further evaluation by radiation safety personnel

## 11.9 Death of radioactive contaminated patient

- There are two particular issues that may arise from the death of a patient. Firstly, the radiation exposure and contamination hazards to the staff involved in handling the cadaver, and secondly, the possibility of an autopsy procedure must be considered.
- The regulations governing the management of cadavers containing radioactivity varies from country to country.
- In India, guidelines provided by AERB on maximum activities of radionuclides for safe disposal of corpses without any special precautions.

## 11.10 Institutional Framework in India

- **BARC (Bhabha Atomic Research Centre)** handles waste from nuclear fuel cycle activities.
- **AERB** regulates radioactive waste management through specific safety codes and guides (e.g., AERB/RF-RW/SC-1).

- **DAE units and healthcare institutions** follow prescribed protocols for radioactive waste handling and disposal. Technical experts from DAE would provide support to Central / State / District Authorities.
- The district authorities shall establish communication channels with the public and other agencies to assure about the safety and security involved in all stages of radioactive waste management.

### Take Home Message:

- ❖ Radioactive contamination is classified into two main types: external and internal
  - ❖ External contamination can be monitoring through the equipment
  - ❖ The aim of External Decontamination is always to prevent contamination to become internalized
  - ❖ Lifesaving will always be the priority
  - ❖ Decontamination should be done on step by step procedure from outside to inside manner
  - ❖ All the wiping to be preserved for dose monitoring
  - ❖ Wound, natural orifices should be taken care to prevent internal contamination
- 
- ❖ Effective radioactive waste management ensures protection of human health and the environment. It requires stringent regulatory control, scientific and technological support, and continuous monitoring as per international and national guidelines

## References (Adapted from)

- IAEA - Guidelines for diagnosis and treatment of internal contamination.  
<https://www.iaea.org/publications/7210/medical-management-of-radiological-emergencies>
- IAEA report on Environmental consequences of the Chernobyl accident and their remediation: twenty years of experience (2006) p. 100
- IAEA TECDOC-1162 ([https://www-pub.iaea.org/MTCD/Publications/PDF/te\\_1162\\_prn.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/te_1162_prn.pdf))
- IAEA (2018). Preparedness and Response for a Nuclear or Radiological Emergency (GSR Part 7).
- IAEA (2005). Manual for First Responders to a Radiological Emergency.
- IAEA (1998) – Diagnosis and Treatment of Radiation Injuries  
<https://www.iaea.org/publications/8669/diagnosis-and-treatment-of-radiation-injuries>  
(Global standards for classification and response to radiation-related skin injuries.)
- IAEA (2018). Classification of Radioactive Waste: IAEA Safety Standards Series No. GSG-1. IAEA, Vienna. <https://www.iaea.org/publications/11114/classification-of-radioactive-waste>
- IAEA Safety Standards Series No. GSR Part 5: Predisposal Management of Radioactive Waste
- Radiation Emergency Medical Management (REMM), HHS/NIH  
<https://remm.hhs.gov/> Details on radionuclide-specific internal injuries and decontamination protocols.
- U.S. Department of Health and Human Services (HHS), Radiation Emergency Medical Management (REMM) – Cutaneous Radiation Injury (CRI)  
<https://www.cdc.gov/radiation-emergencies/hcp/clinical-guidance/cri.html>(Detailed classification and clinical management of CRI.)
- WHO (2017). Manual for First Responders to a Radiological Emergency (2nd ed.)
- WHO Guidelines: Safe Management of Wastes from Health-Care Activities
- IAEA Safety Guide GSG-7; WHO Radiological Public Health Response Manual
- WHO – Health Risk Assessment of Radionuclides  
([https://iris.who.int/bitstream/handle/10665/78218/9789241505130\\_eng.pdf](https://iris.who.int/bitstream/handle/10665/78218/9789241505130_eng.pdf))
- ICRP Publication 78 – Individual Monitoring for Internal Exposure of Workers  
<https://www.icrp.org/publication.asp?id=ICRP%20Publication%2078>

- AERB <https://www.aerb.gov.in/storage/uploads/documents/regdoc00bxT.pdf>
- AERB Safety Code AERB/RF-RW/SC-1: Management of Radioactive Waste
- BARC Publications: Waste Management Practices in India
- BARC Emergency Handbook; WHO Guidance for Radiological Emergencies
- AERB Radiation Monitoring Guidelines;
- Bhabha Atomic Research Centre (BARC). (2009). Guidelines for Medical Management of Radiation Emergencies.
- Images:
  1. Fig.no. 11.1 [IAEA report on Environmental consequences of the Chernobyl accident and their remediation: twenty years of experience (2006) p. 100]
  2. Fig.no. 11.2,11.3 (adapted from IAEA)
  3. Fig.no. 11.4 (BARC)
  4. Fig.no. 11.5

([http://www.aerb.gov.in/T/forms/regforms/nuclear\\_medicine/docs/NMPlans.pdf](http://www.aerb.gov.in/T/forms/regforms/nuclear_medicine/docs/NMPlans.pdf))

### **Suggested Reading**

- Bhabha Atomic Research Centre (BARC). (2009). Guidelines for Medical Management of Radiation Emergencies.
- IAEA (2020) Medical Management of Radiation Injuries ([https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1891\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1891_web.pdf))
- IAEA (2024) Generic Procedures for Medical Response During a Nuclear or Radiological Emergency ([https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-Medical%20\(2024\)\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-Medical%20(2024)_web.pdf))
- BARC Publications: Waste Management Practices in India

## Chapter 12

### Topic: Medical Management of Internal Contamination

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand internal contamination and entry routes
- Learn prevention, detection, and treatment
- Learn decontamination and sampling protocols

#### 1. Introduction

Internal contamination refers to the incorporation of radioactive material into the human body through various routes (inhalation or ingestion or open wounds), leading to potential exposure of internal organs and tissues to ionizing radiation. Unlike external exposure, where the radiation source remains outside the body, internal contamination can result in prolonged and potentially more harmful biological effects. Internal contamination continues until the radioactive material decays, is flushed from the body by natural processes, or is removed by medical countermeasures.

According to the International Atomic Energy Agency (IAEA) and the Atomic Energy Regulatory Board (AERB), internal contamination becomes a concern particularly during nuclear or radiological emergencies, industrial accidents, or improper handling of unsealed radioactive sources.

#### 2. Routes of Entry

Each route determines the distribution and retention of the radionuclide within specific organs or tissues (e.g., iodine in the thyroid, plutonium in bone or liver). There are four principal routes by which radionuclides can enter the human body:

- ❖ **Inhalation:** Radioactive aerosols or gases may be inhaled and deposited in the respiratory tract. Depending on the particle size and solubility, these may lodge in the upper airway, tracheobronchial tree, or alveoli, and may subsequently translocate to the bloodstream or regional lymph nodes.
- ❖ **Ingestion:** Radionuclides may enter the gastrointestinal tract through contaminated food, water, or hand-to-mouth activity. Once ingested, they can be absorbed through the gut wall into systemic circulation.
- ❖ **Absorption through Skin and Wounds:** Damaged or broken skin can act as a direct pathway for radionuclides to enter the bloodstream. Lipophilic or highly soluble compounds may also penetrate intact skin.
- ❖ **Injection or Embedded Contaminants:** In industrial accidents or terrorism-related events, fragments containing radionuclides may become embedded in tissues, or be introduced via injection, either accidentally or intentionally.

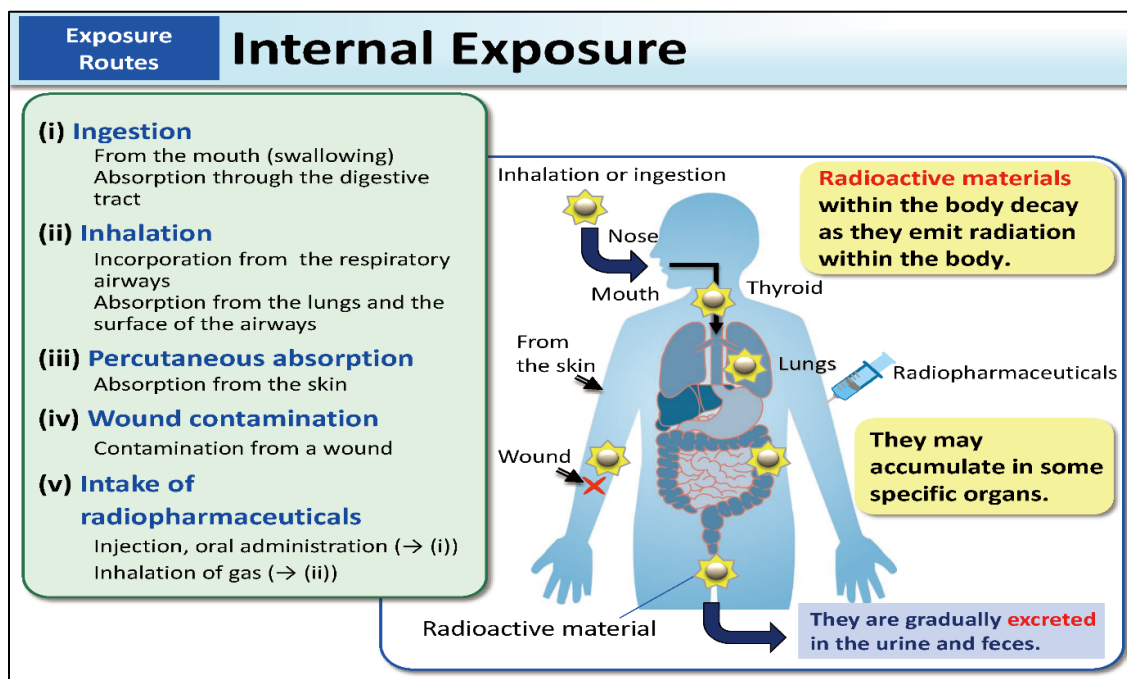


Fig.no. 12.1 – Routes of entry

### 3. Stages of internal contamination

Internal contamination progresses through several stages.

- ❖ The first stage, **intake**, occurs when radioactive material enters the body, which may happen via the gastrointestinal tract through ingestion, the respiratory system via inhalation, or through wounds and, in some cases, intact skin.
- ❖ The second stage, **uptake**, involves the absorption of radionuclides into the bloodstream or lymphatic system, allowing them to be transported throughout the body.
- ❖ In the **deposition stage**, radioactive substances accumulate in specific target organs or tissues, depending on their chemical properties and biological behavior.
- ❖ Finally, **elimination** refers to the removal of radioactive material from the body through metabolic processes, excretion in urine or feces, or natural decay over time.

Understanding these stages is critical for timely monitoring, medical intervention, and application of decorporation therapies to limit radiation dose.

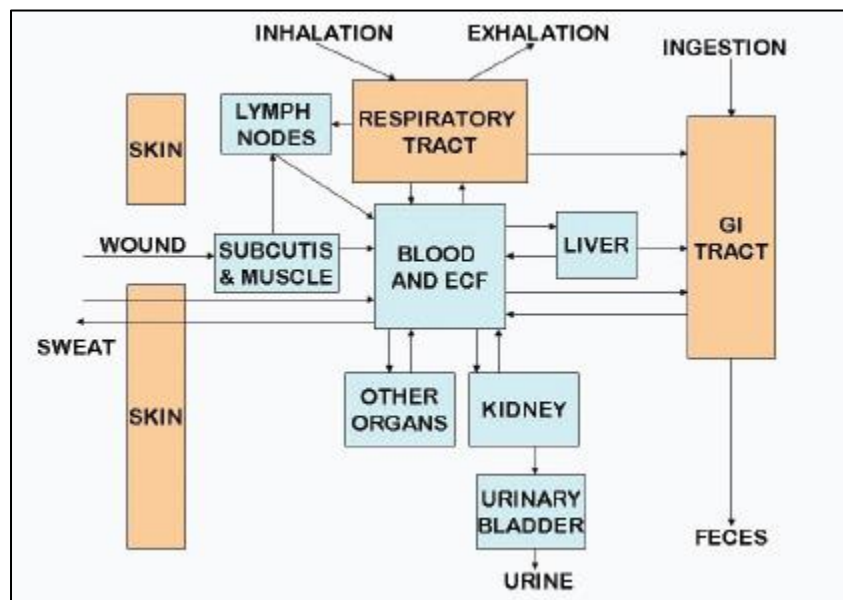


Fig.no.12.2 --Example compartmental model representation of a radionuclide bio-kinetic model

#### 4. Extent of Hazard

When a radioactive material is in a living organism, the material can be removed from a particular organ or location by two mechanisms, as illustrated in the figure 12.3. One is the normal radioactive decay, and the other is biological transport or elimination from the specific site.

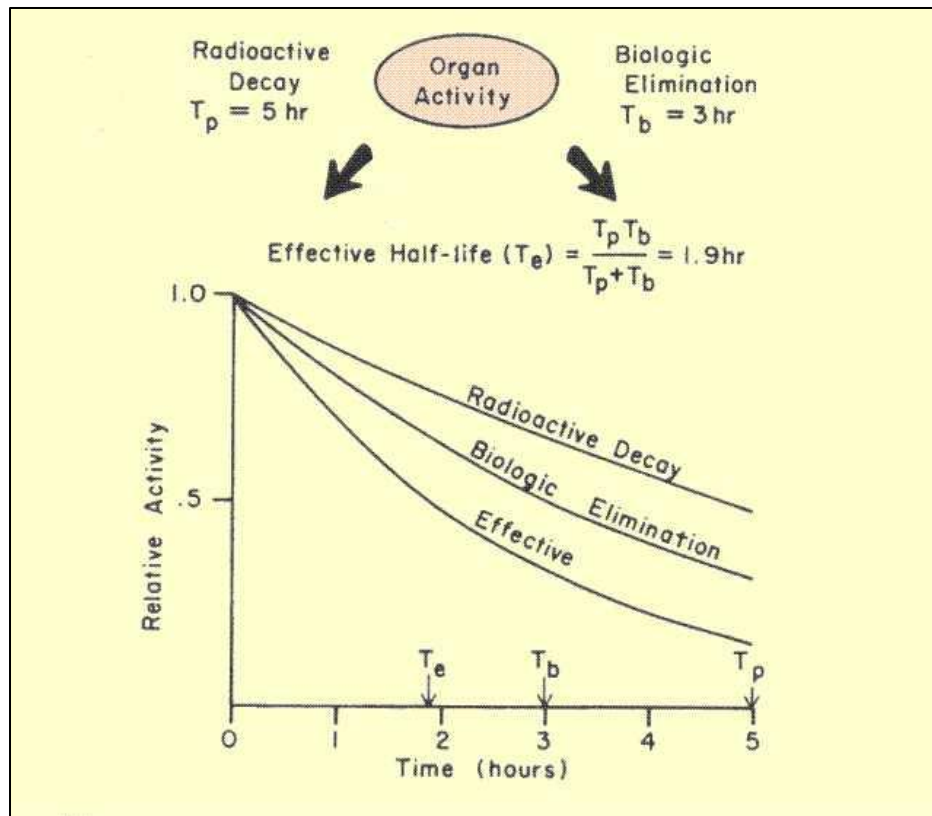


Fig.no.12.3-- Relationship of Effective Lifetime to Rates of Radioactive Decay and Biological Elimination

#### 4.1 Factors Determining the Extent of Contamination Hazard

- ❖ **Amount of radionuclide present:** The larger the quantity of radioactive material, the greater the potential for contamination and radiation dose.
- ❖ **Energy and type of radiation emitted:** The biological impact and hazard of radioactive material depend on the type and energy of radiation it emits. Alpha, beta, and gamma radiations differ in their penetration abilities and the extent of tissue damage they can cause. High-energy gamma emitters can penetrate deeply and pose a significant external hazard, whereas alpha emitters, which have very low penetration, primarily present a risk if ingested, inhaled, or absorbed internally, causing localized internal damage. Understanding these characteristics is essential for assessing exposure risks and implementing appropriate protective measures.

❖ **Biological and physical half-life:**

- **Physical half-life:** Time taken for half the radioactive atoms to decay; longer half-lives prolong contamination risk.
- **Biological half-life:** Time taken for the body to eliminate half of the radionuclide; determines how long it remains in critical organs or tissues.

❖ **Critical organ involved:** For each radionuclide, there is often a critical organ that receives the highest radiation dose, making it the most susceptible to damage. For example, iodine-131 predominantly accumulates in the thyroid gland, while strontium-90 tends to deposit in bones. Identifying the critical organ is essential for assessing potential health effects, guiding medical monitoring, and implementing targeted protective or therapeutic interventions.

❖ **Properties of the radionuclide:** Chemical form, solubility, volatility, and particle size influence its environmental persistence, uptake, and spread.

## 5. **Medical Management of Internal Contamination:**

The clinical management of internal contamination involves a structured, evidence-based approach that ensures immediate stabilization of the patient while simultaneously initiating contamination control and diagnosis.

### 5.1 **Detection of Internal Contamination**

Detecting internal contamination involves measuring the presence and quantity of radioactive material within the body, which, requires a multi-modal approach that integrates clinical evaluation, laboratory bioassays, and direct radiation detection methods:

- ❖ **Clinical History and Incident Data:** A detailed account of the time, duration, type, and route of potential exposure helps guide the diagnostic process.
- ❖ **Bioassay Sampling:** Bioassay sampling is essential for assessing internal contamination and the systemic distribution of radionuclides. Urine and fecal samples are commonly collected to estimate systemic absorption and excretion kinetics. A 24-hour urine collection is particularly important for assessing the internal burden of soluble radionuclides, while fecal samples

provide information on ingestion or biliary excretion of insoluble or particulate radionuclides. Nasal swabs can detect inhaled radioactive particles, especially within the first few hours after exposure. **Blood samples help identify early systemic distribution of radionuclides and can be collected using standard clinical precautions without special considerations.** In cases where contamination occurs through breaks in the skin, wound swabs and tissue samples may also be obtained to assess localized uptake.

- ❖ **Whole-body and Wound Counting:** Use of detectors like gamma spectrometry to identify and quantify radionuclide deposition in tissues or at the site of entry or Sodium Iodide (NaI(Tl)) Scintillation Detectors for rapid detection of medium- and high-energy gamma emitters or wound counters using small scintillation probes for superficial or embedded contamination.
- ❖ **Radiation Monitoring Equipment:** Hand-held devices such as Geiger-Müller counters, scintillation probes, and spectrometers are used to assess contamination levels.

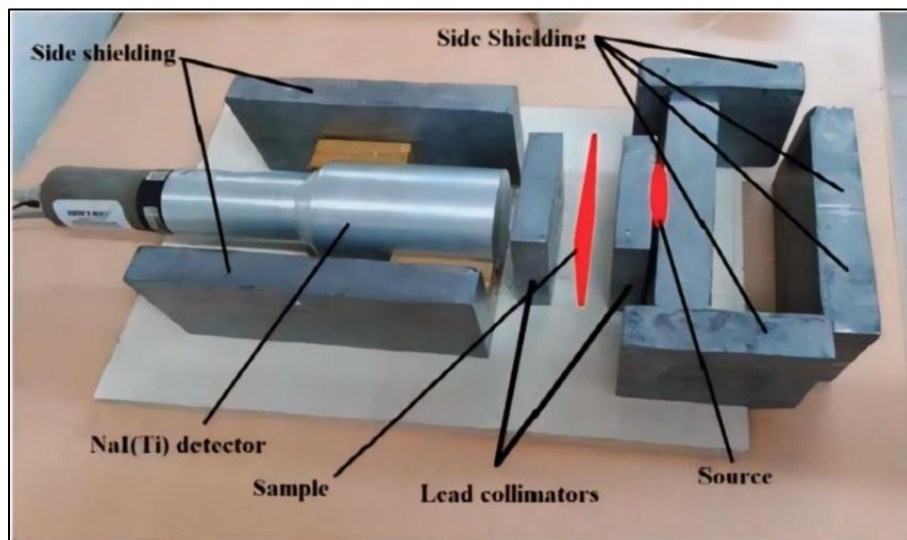


Fig.no. 12.4 – Sodium Iodide Scintillation Detector and its component



Fig. no. 12.5-- Handheld Gamma Spectrometer

## 5.2 Prevention of Internal Contamination

Preventing internal contamination is paramount, especially in radiation emergencies or during the handling of unsealed radioactive sources. Prevention strategies include:

- ❖ **Use of PPE:** Respiratory masks, gloves, protective suits, and eye protection prevent inhalation, ingestion, and dermal absorption.
- ❖ **External Decontamination:** Immediate and thorough washing of contaminated skin and hair prevents radionuclides from entering the body via wounds or mucous membranes.
- ❖ **Engineering Controls:** Proper ventilation, use of fume hoods, and containment systems in laboratories and nuclear facilities help minimize airborne exposures.
- ❖ **Pharmacological Blockade:** Administration of specific agents can prevent absorption or facilitate competitive inhibition. Examples include potassium iodide (KI) to block radioactive iodine uptake in the thyroid, Prussian blue for cesium, and calcium or zinc DTPA for transuranic elements.
- ❖ **Workplace Monitoring and Training:** Monitoring air, surfaces, and personnel regularly, workplace protocols and Standard Operating Procedures (SOPs) and conducting regular drills and training, ensures preparedness.

### 5.3 Internal Decontamination Procedure

- ❖ Internal decontamination depends on the route of entry and the physicochemical properties of the radionuclide. In cases of **ingestion**, management differs for soluble and insoluble radionuclides.
  - **Soluble radionuclides** may be rendered less absorbable by insolubilizing them when possible, diluted using stable isotopes—such as administering stable iodine to block uptake of radioactive iodine—and treated with specific therapeutic agents including ion-exchange resins, gels, or antacids to limit absorption.
  - For **insoluble radionuclides**, early gastric emptying through emesis or lavage (when clinically safe) may be considered, followed by catharsis to accelerate gastrointestinal clearance.
- ❖ When radionuclides are **inhaled**, treatment again depends on solubility.
  - **Insoluble** particles may be mobilized using aerosolized expectorants and by encouraging natural mucociliary clearance mechanisms; in rare and severe cases, lung lavage may be required.
  - **Soluble** radionuclides inhaled into the respiratory tract can be managed with specific chelating or binding agents such as aerosolized DTPA, alongside systemic therapies designed to enhance elimination.
- ❖ For **contamination through broken skin or wounds**, the wound should first be **isolated from clean areas to prevent further spread**, then irrigated thoroughly with sterile saline or water. Persistent contamination may necessitate surgical excision of affected tissue. Wounds must be **monitored regularly for residual activity**, and if contamination continues despite intervention, referral to a specialized center is recommended.
- ❖ If **radionuclides contact intact skin**, external decontamination procedures should be performed first. **When dealing with radionuclides capable of penetrating intact skin, additional measures may be required to block systemic absorption.** In all cases, samples such as tissues, washings, and used instruments should be preserved for radio-assay and ongoing monitoring. Once internal contamination has been cleared or reduced to acceptable levels, routine treatment may proceed; if not, the case should be escalated for advanced care.

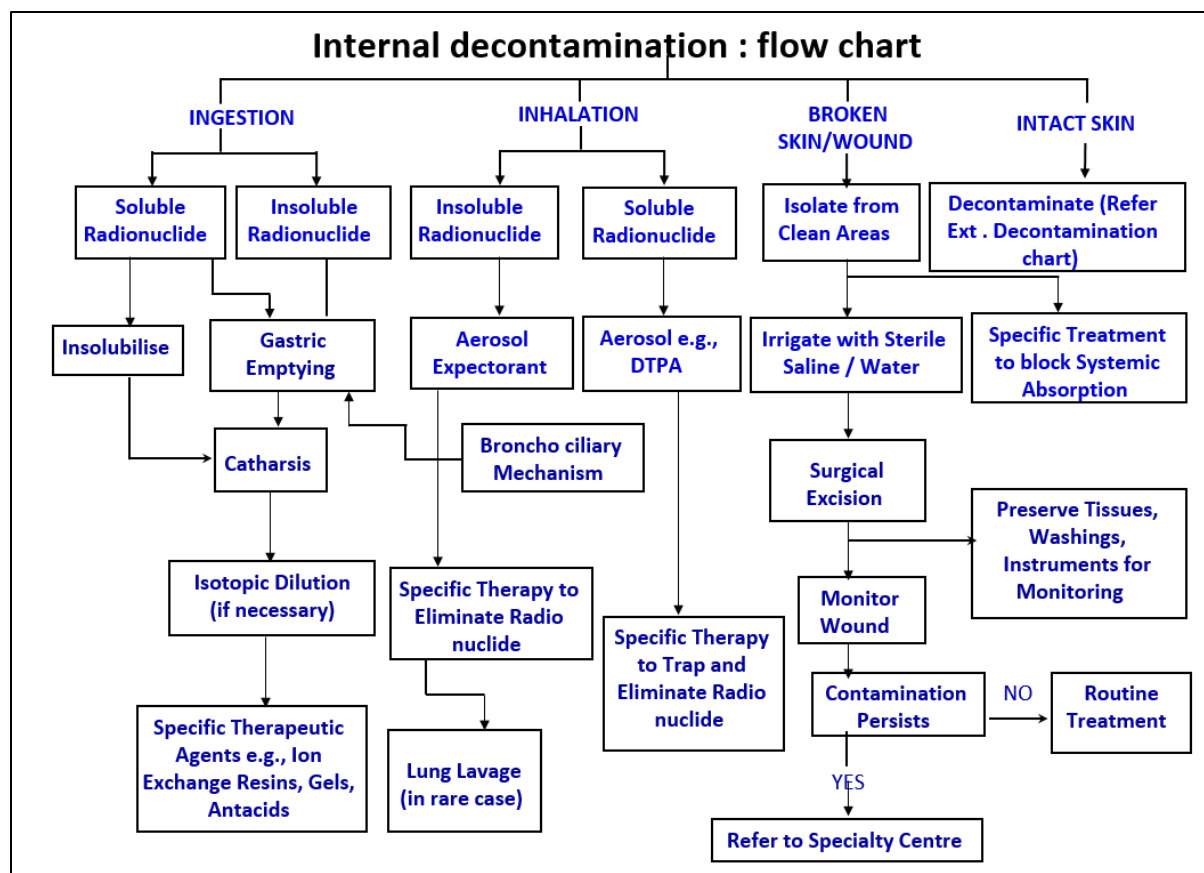


Fig.no. 12.6-- Internal Decontamination Flow Chart

#### 5.4 Current methods of Treatment of Internal Contamination

Treatment of internal contamination focuses on limiting radionuclide absorption, enhancing its elimination, or blocking its uptake by critical organs. One approach is **saturation of the target organ**, such as administering potassium iodate or potassium iodide to saturate the thyroid gland and prevent uptake of radioactive iodine isotopes. Another method involves forming **stable complexes with radionuclides** at the site of entry or within body fluids, enabling rapid excretion; an example is the use of Diethylene Triamine Pentaacetic Acid (DTPA) to chelate plutonium and related transuranic elements. Treatment may also involve **accelerating the metabolic cycle of a radionuclide through isotope dilution**, such as promoting increased water intake to enhance excretion of tritium ( $^3\text{H}$ ). In some cases, **radionuclides can be precipitated within the gastrointestinal tract**, reducing absorption and promoting fecal elimination—for instance, administering barium sulfate to precipitate strontium. Additionally, **ion-exchange mechanisms**

can be used to trap radionuclides in the gut, exemplified by the use of Prussian blue to bind cesium-137 ( $^{137}\text{Cs}$ ) and enhance its excretion. These methods form the core of current medical countermeasures for internal contamination, tailored to the chemical behavior and biological kinetics of each radionuclide.

## 5.5 Role of Therapeutic Action for Absorbed Dose Formation

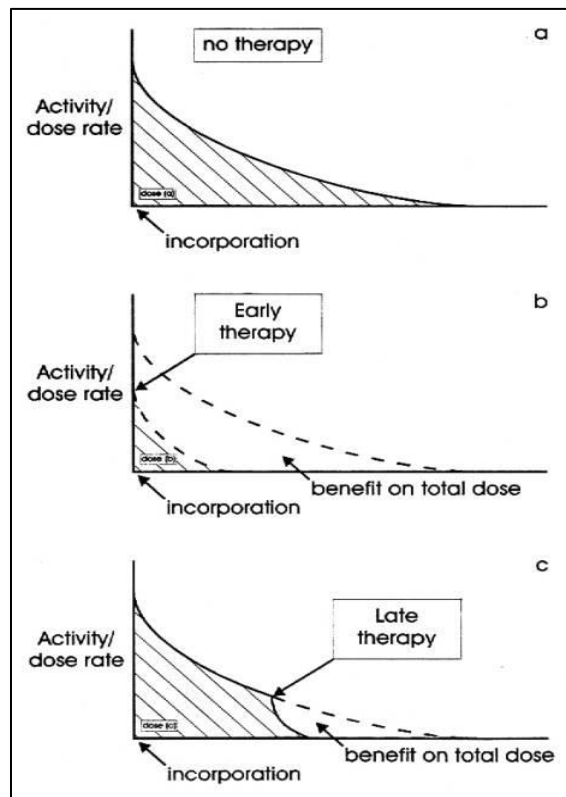


Fig.no. 12.7 – Role of therapeutic action for absorbed dose formation

Figure 12.7 illustrates how therapy timing influences the absorbed dose after radionuclide incorporation.

### ❖ No Therapy

- After radionuclide incorporation, the activity/dose rate decreases naturally over time due to:
  - Radioactive decay

- Biological clearance (excretion, metabolism)
- The hatched area under the curve represents the total absorbed dose received by the body.
- Since no intervention occurs, the body accumulates the maximum possible dose from the incorporated radionuclide.

#### ❖ **Early Therapy**

- If treatment (e.g., chelation, blocking agents like Potassium Iodide, Prussian Blue, DTPA) is started immediately after incorporation, the radionuclide is removed more quickly.
- This results in a steeper decline in activity/dose rate.
- The shaded dose area (Dose B) is much smaller than in (a).
- Benefit: A significant reduction in the total absorbed dose, because early action prevents the radionuclide from being retained in critical organs.

#### ❖ **Late Therapy**

- If treatment is initiated later, the radionuclide has already delivered part of its radiation dose.
- Therapy still helps by enhancing elimination, but the benefit is smaller than with early intervention.
- The dose reduction is visible but limited, since the initial phase of high dose rate exposure has already passed.

### **5.6 Clinical Relevance**

- ❖ In radiological emergencies involving internal contamination, the timing of medical countermeasures is critical.
- ❖ Agents like KI (for radioactive iodine), Ca-DTPA/Zn-DTPA (for actinides), Prussian Blue (for Cs-137, Tl-201) are most effective if given immediately after exposure.

**6. Decorporation:** Decorporation refers to the therapeutic process of enhancing the elimination of radionuclides from the body, thereby reducing the internal dose. This is achieved using specific pharmacological agents or supportive interventions:

- ❖ **Blocking Agents:** Substances like potassium iodide (KI) saturate the thyroid to prevent uptake of radioactive iodine.
- ❖ **Chelation Therapy:** Agents such as diethylenetriaminepentaacetic acid (DTPA) bind to transuranic metals (e.g., plutonium, americium) to facilitate urinary excretion.
- ❖ **Ion Exchange Mechanisms:** Prussian blue acts within the gastrointestinal tract to bind Cesium-137 and Thallium, reducing enterohepatic circulation.
- ❖ **Dilution and Forced Diuresis:** Increasing fluid intake and promoting diuresis enhances the excretion of tritiated water or other water-soluble radionuclides.

The effectiveness of decorporation is time-sensitive and depends on the chemical form, route of entry, and prompt administration of appropriate agents.

Sr. No.	Radionuclide	Mode of contamination	Target Organ	Specific Treatment
1	Iodine	Inhalation/ Ingestion	Thyroid	Potassium Iodate ( $KIO_3$ ) Tablet (170 mg) Dose Adults and adolescents (over 12 years) - One Tablet Children (3 to 12 years) - ½ Tablet Infants (1 month to 3 years) - ¼ Tablet Neonates (birth to 1 month) - 1/8 Tablet
2	Strontium	Ingestion / wound	Bones	Calcium Gluconate Ampoules of 10 mL containing 100 mg/mL (10%). Dose in adults 6 to 10 ampoules orally per day. Intravenous use in adults 2 gm calcium gluconate in 500 mL 5% glucose per day, up to 6 days. Ammonium chloride

				Tablets 0.5 gm of ammonium chloride; oral use. Dose in adults 6 gm per day; 4 tablets every 8 hours
3	Cesium	Inhalation/ Ingestion	Whole body	Radiogardase Cesium (Insoluble Prussian Blue) Capsules supplied as 0.5 gm of insoluble Prussian Blue. Dose in adults 1 gm to 3 gm three times a day orally in a little water.
4	Tritium	Ingestion/ Inhalation/ Intact skin	Whole body	Forced Diuresis To speed up the body water turnover cycle, liquid intake has to be increased (3 to 4 L/day) to stimulate diuresis.
5	Cobalt	Inhalation/ Ingestion	Liver	Ca-DTPA Ca- DTPA from 0.5 gm (half an ampoule) to 1 gm, given by slow intravenous injection over a period of 3 - 4 minutes or by intravenous infusion diluted in 100 - 250 mL of 5% dextrose in water (D5W), Ringer's lactate or normal saline Alternative treatment Cobalt gluconate (care needs to be taken with the vasodilator action in blood vessels), Dimercapto Succinic Acid (DMSA), EDTA and N-acetyl-cysteine
6	Uranium	Ingestion/ Inhalation / Wound	Kidney and Bone	Sodium Bicarbonate Intravenous isotonic sodium bicarbonate 14% in 250 mL, slow intravenous injection or 2 bicarbonate tablets orally every 4 hours until urine reaches a pH 8 to 9.
7	Plutonium and Transplutronics	Inhalation/ Ingestion/ Wound	Bone and Liver	Ca – DTPA Ca-DTPA from 0.5 gm (half an ampoule) to 1 gm, given by slow intravenous injection over a period of 3 -4 minutes or by intravenous infusion diluted in 100 - 250 mL of 5%

				dextrose in water (D5W), Ringer's lactate or normal saline
--	--	--	--	--

Table no. 12.1- Specific antidotes for various Radionuclides (adapted from IAEA)

## 7. Bioassay Sampling

Bioassay sampling is an essential technique used to assess radioactive contamination within the human body. It involves collecting and analyzing biological samples—such as urine, feces, or blood—to detect and quantify internalized radioactive materials. This method plays a critical role in evaluating potential radiation exposure, ensuring compliance with occupational safety standards, and guiding decisions related to medical management and protective measures for exposed individuals. Bioassay assessments can be conducted through two primary approaches: **direct monitoring**, which measures radiation emitted from the body using instruments such as whole-body counters, and **indirect monitoring**, which involves laboratory analysis of biological samples to determine the presence of radionuclides. Together, these methods provide valuable information for understanding internal contamination levels and planning appropriate interventions.

## Take Home Message:

- ❖ Internal contamination can happen through Inhalation, Injection, Skin Absorption
- ❖ Internal decontamination outcome depends upon the effective half - life of Radionuclide
- ❖ Early administration of Decorporating agents have better outcome
- ❖ Potassium Iodate tablet administration should be done before actual exposure
- ❖ To recap, the Standard Operating Procedure (SOP) for Decontamination are as under:
  - Triage: Identify contamination using handheld detectors.
  - Stabilization: Address life-threatening injuries.
  - Clothing Removal: Eliminates ~90% of contamination.
  - Washing: Gentle with soap and water.
  - Protect Wounds: Use waterproof dressings.
  - Collect Samples: For internal dose assessment.
  - Begin Decorporation: If indicated.
  - Document and Report: Exposure and intervention.
  - Manage Waste: As per radioactive waste protocols.
  - Efficacy of treatment is ascertained through Bioassay sampling
- ❖ Bioassay assessments use direct body monitoring or laboratory analysis of biological samples to evaluate internal contamination and guide interventions.

## References (Adapted from)

- IAEA (2004) Practical Radiation Technical manual ([https://www-pub.iaea.org/MTCD/Publications/PDF/PRTM-2r1\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/PRTM-2r1_web.pdf))
- REMM (U.S. Department of Health and Human Services) Internal Contamination and Treatment. [https://remm.hhs.gov/contamimage\\_top3.htm](https://remm.hhs.gov/contamimage_top3.htm)
- IAEA (2020) Medical Management of Radiation Injuries ([https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1891\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1891_web.pdf))

- IAEA (2024) Generic Procedures for Medical Response During a Nuclear or Radiological Emergency ([https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-Medical%20\(2024\)\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-Medical%20(2024)_web.pdf))
- WHO. Health Risk Assessment of Radionuclides. <https://www.who.int/teams/environment-climate-change-and-health/radiation-and-health/non-ionizing/emf/health-risk>
- UNSCEAR. Sources and Effects of Ionizing Radiation. <https://www.unscear.org/unscear/en/publications.html>
- ICRP Publication 78. Individual Monitoring for Internal Exposure. <https://www.icrp.org/publication.asp?id=ICRP%20Publication%2078>
- National Academies of Sciences, Engineering, and Medicine. 2012. Analysis of Cancer Risks in Populations Near Nuclear Facilities: Phase 1. Washington, DC: The National Academies Press. <https://nap.nationalacademies.org/read/13388/chapter/17#379>
- CDC. Radiation Emergencies: Internal Contamination. <https://www.cdc.gov/radiation-emergencies/infographic/contamination-versus-exposure.html>
- IAEA (2005). Manual for First Responders to a Radiological Emergency. IAEA Safety Standards Series No. EPR-First Responders.
- IAEA (2002). Diagnosis and Treatment of Radiation Injuries. IAEA Training Course Series No. 2.
- IAEA (2018). Preparedness and Response for a Nuclear or Radiological Emergency. General Safety Requirements No. GSR Part 7.
- WHO (2023). REMPAN Guidelines for the Medical Management of Radiological Emergencies. World Health Organization, Radiation Emergency Medical Preparedness and Assistance Network.
- [https://www.researchgate.net/figure/NalTI-detector-and-its-components-48\\_fig3\\_382148910](https://www.researchgate.net/figure/NalTI-detector-and-its-components-48_fig3_382148910)
- AERB (2014). Safety Guide on Radiation Protection in the Use of Nuclear Medicine (AERB/RF-RP/NM/SG-1).
- AERB (2008). Guidelines for Medical Management of Radiation Accidents.

- BARC (2011). Radiation Emergency Medical Preparedness: Handbook for Healthcare Providers. Health, Safety and Environment Group, Bhabha Atomic Research Centre
- International Atomic Energy Agency (IAEA). (2018). Preparedness and Response for a Nuclear or Radiological Emergency (GSR Part 7).
- WHO (2017). Manual for First Responders to a Radiological Emergency (2nd ed.).
- BOOKLET to Provide Basic Information Regarding Health Effects of Radiation (3rd edition)
- IAEA (2018). Preparedness and Response for a Nuclear or Radiological Emergency (GSR Part 7). Vienna: IAEA.
- IAEA (2005). Manual for First Responders to a Radiological Emergency. Vienna: IAEA.
- Bhabha Atomic Research Centre (BARC). (2009). Guidelines for Medical Management of Radiation Emergencies. Mumbai: BARC.
- Medical management of persons internally contaminated with radionuclides in a nuclear or radiological emergency: A Manual for Medical Personnel: International Atomic Energy Agency
- Images:
  1. Fig.no. 12.1 (BOOKLET to Provide Basic Information Regarding Health Effects of Radiation 3rd edition)
  2. Fig.no. 12.2 (Adapted from ICRP 1997)
  3. Fig.no. 12.3 (<http://www.sprawls.org/ppmi2/RADIOACT/>)
  4. Fig.no. 12.4 (<https://link.springer.com/article/10.1007/s44274-024-00080-y>)
  5. Fig.no. 12.5 (<https://gammadata.se/wp-content/uploads/2024/01/Identifinder-R440.png>)
  6. Fig.no. 12.6, 12.7 (IAEA)

### **Suggested Reading**

- Booklet to Provide Basic Information Regarding Health Effects of Radiation 3rd edition (<https://www.env.go.jp/en/chemi/rhm/basic-info/1st/03.html>)
- IAEA (2020) Medical Management of Radiation Injuries ([https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1891\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1891_web.pdf))

- IAEA (2024) Generic Procedures for Medical Response During a Nuclear or Radiological Emergency ([https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-Medical%20\(2024\)\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-Medical%20(2024)_web.pdf))

## Chapter 14

### On-site activities: Managing the scene

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Recognize signs of a radiological emergency.
- Assess and secure a radiation accident scene.
- Select appropriate PPE and radiation detection tools.
- Implement radiological control measures on-site.
- Set up and manage a Reception Centre (RC).
- Handle and decontaminate contaminated patients.

#### 1. Introduction

Radiological emergencies—whether from industrial accidents, transport mishaps, malicious attacks, or natural disasters—require rapid, coordinated response to protect life and limit contamination. Effective on-site management follows a structured, principle-based approach: detect hazards, assess damage, protect responders, contain contamination, treat victims, and establish centralized support centers. This chapter outlines critical steps responders take when managing a radiological incident on-site.

#### 2. On-site decontamination in Radiological and Nuclear emergencies

In the event of a Radiological and Nuclear (RN) emergency, rapid and effective on-site decontamination is crucial to minimize harm to individuals and prevent the spread of contamination.

#### 3. Indications of a possible radiation emergency

*“When in doubt, always assume radiological involvement until proven otherwise.” - IAEA*

According to the IAEA Manual for First Responders to a Radiological Emergency (2006) and IAEA Safety Standards (GSR Part 7, 2015), responders should be aware of a range of signs and circumstances that may indicate a radiation-related event. These are grouped as follows:

❖ **Suspicious Devices or Situations**

- Suspicious devices or situations in radiological and nuclear emergencies include any scenario that may involve the intentional release of radioactive material.
- This includes **suspected or actual bombs**, such as explosive devices that could be associated with radioactive substances, commonly referred to as radiological dispersal devices (RDDs) or “dirty bombs.”
- **Credible threats or messages** received from authorities or intelligence agencies warning of possible use of radioactive sources also fall into this category.
- Additionally, devices or equipment that appear **designed to spread contamination**, such as unusual containers, sprayers, or explosive dispersal mechanisms, should be treated with extreme caution.
- Early identification and reporting of such situations are critical for protecting responders and the public.

❖ **Environmental and Visual Indicators**

- Environmental and visual cues can help identify potential radiological hazards.
- **Signs of contamination** may include unexplained powders, liquid spills, debris, or smoke in confined or public areas.
- **Radiation symbols**, such as trefoil markings on packages, containers, or areas, may indicate the presence of radioactive material, particularly if they appear misplaced, abandoned, or damaged.



Fig. no.14.1—Radiation Symbol

- **Lost or orphan sources**—radioactive sources found in unexpected locations, missing from inventory, or visibly damaged, leaking, or involved in a fire—also serve as critical warning indicators. Recognizing these signs promptly is essential for early hazard assessment, responder safety, and the initiation of appropriate protective measures.

❖ **Instrument Readings and Technical Findings**

- Instrument readings and technical assessments provide critical confirmation of radiological hazards.
- **Elevated radiation levels** detected by portable gamma dose rate meters, showing values significantly above background, indicate potential contamination or radioactive material presence.
- The **presence of neutron radiation**, although rare, is a highly significant indicator of extremely hazardous material, such as fissile or special nuclear material.
- Finally, **assessment by radiological experts** or authorized monitoring teams provides confirmation and guidance, ensuring that accurate information informs the response and protective measures. These findings are essential for directing emergency operations, establishing safe zones, and protecting both responders and the public.

❖ **Medical and Health Indicators**

- In radiological and nuclear events, radiation exposure typically does not cause immediate burns, injuries, or sudden death.
- If such acute effects are observed, they are more likely the result of other hazards, such as chemical exposure, thermal burns, or trauma from flying debris.

- **Radiation-specific symptoms** may develop within hours to days and include **skin erythema or burns without an external heat source, nausea, vomiting, or dizziness** (which may indicate the onset of Acute Radiation Syndrome), and, in cases of very high exposure, **eye irritation or sudden cataract formation**.
- Recognizing these indicators is crucial for timely diagnosis, triage, and management of affected individuals.

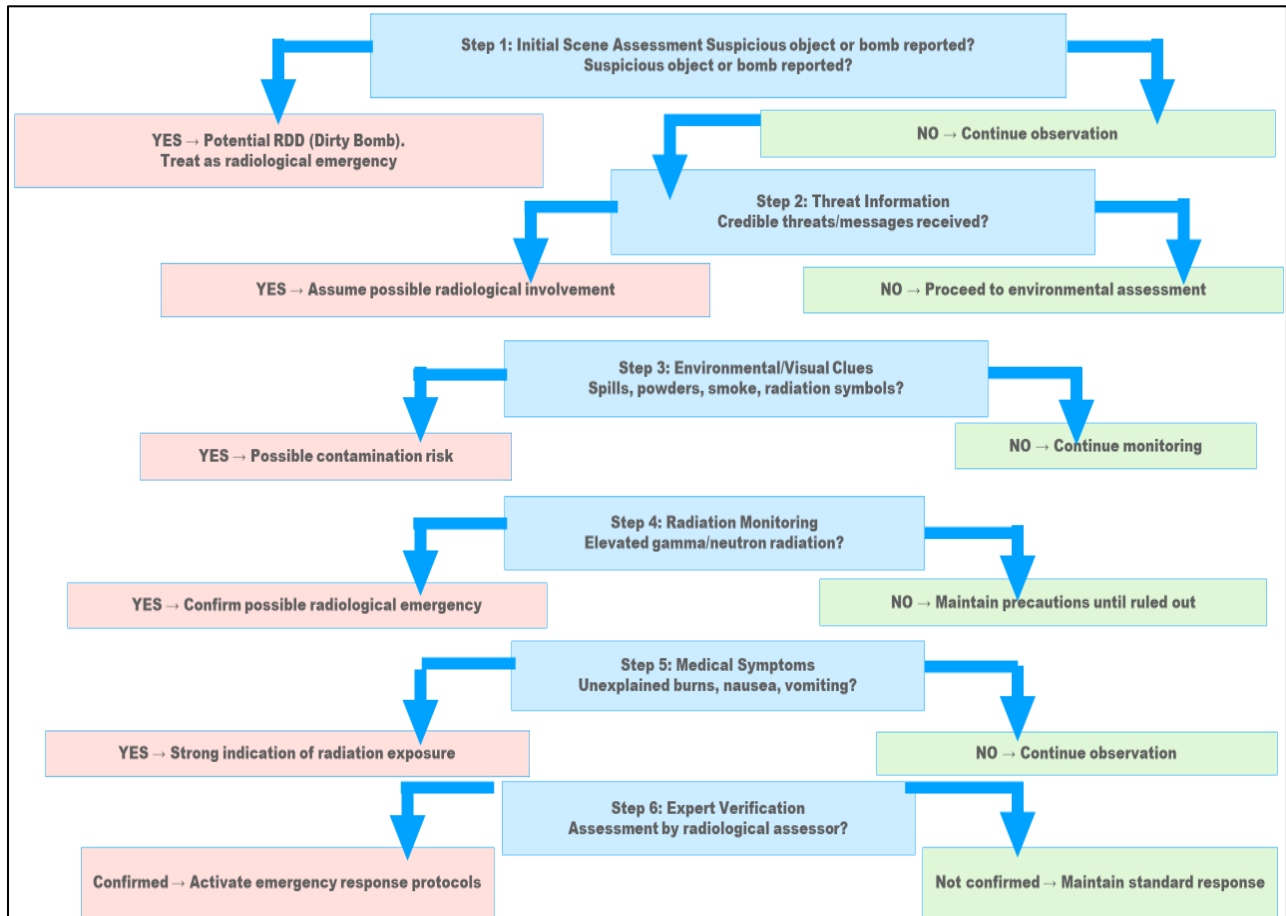


Fig. no.14.2—Flowchart: Identifying a Possible Radiation Emergency

**4. Assessment of the accident scene:** Effective assessment of the accident scene is the first critical step in responding to a radiological emergency. It ensures responder safety, minimizes exposure, and enables informed decision-making for medical and public health actions.

#### 4.1 Key elements of scene assessment

- ❖ **Initial Survey:** The first step involves **identifying potential hazards**, which may include radiological, chemical, biological, explosive, or fire-related threats. It is also essential to estimate the number of people affected and determine the mode of radiation or chemical release.
- ❖ **Establishing the Perimeter:** **Setting an incident perimeter** is critical for safety, recovery, and control of the affected area. Considerations include **physical factors** such as the type and severity of the incident (Radiological Dispersal Device, Improvised Nuclear Device, Radiological Exposure Device, or reactor accident), co-existing hazards, and infrastructure risks; **medical factors** related to responder and **public safety**; and **security** factors like protecting forensic evidence, controlling access points, and safeguarding critical institutions. Boundaries may be adjusted as radiation levels decay.
- ❖ **Responder Safety:** The protection of responders is a **priority**. Visual assessment from a **safe distance** should include noting structural damage, smoke, vapors, spills, debris, casualties, and radiation hazard symbols. Entering the site without **proper protective equipment** must be avoided.
- ❖ **Command and Coordination:** Competent authorities should be notified immediately (AERB, 2009), and an **Incident Command System (ICS)** established to organize the response. The event should be classified according to the INES scale for appropriate reporting and resource allocation.
- ❖ **Documentation:** Accurate recording of radiation levels, **responder entry and exit times**, **casualty details**, and **suspected source information** is essential for accountability and future analysis.
- ❖ **Environmental and Situational Awareness:** **Continuous monitoring** of wind direction, avoiding low-lying areas with pooled water or debris, and the **use of signage and barriers to restrict civilian access** are important measures for safety.

In continuation of the discussion as elaborated in Chapter 4 of this training module, regarding the INES scale, which is required for the assessment and categorization of a radiological and nuclear event.

#### 4.2 Categorizing a radiological and nuclear event:



Fig. no. 14.3 -- International Nuclear and Radiological Event Scale (INES)

INES Level	People and Environment	Radiological Barriers and Control	Defense in Depth
7 Major Accident	Major release of radioactive material with widespread health and environmental effects. Requires implementation of planned and extended countermeasures.	-	-
6 Serious Accident	Significant release of radioactive material likely to require full implementation of planned countermeasures.	-	-
5 Accident with Wider Consequences	Limited release of radioactive material likely to require partial implementation of planned	Severe damage to reactor core. Release of large	-

	countermeasures. Several deaths from radiation.	quantities of radioactive material within an installation.	
<b>4 Accident with Local Consequences</b>	Minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls. At least one death from radiation.	Fuel melt or damage to fuel resulting in more than 0.1% release of core inventory.	Significant damage to safety systems or procedures.
<b>3 Serious Incident</b>	Exposure in excess of ten times the statutory annual limit for workers. Non-lethal deterministic health effects (e.g., burns).	Exposure in excess of regulatory limits. Significant contamination within the facility.	Near accident (with no safety provisions remaining). Severe spread of contamination.
<b>2 Incident</b>	Exposure of a member of the public in excess of statutory annual limits.	Radiation levels in controlled areas significantly above the limit.	Significant failure in safety provisions, but with sufficient remaining barriers.
<b>1 Anomaly</b>	-	Minor problems in components or systems affecting safety.	Deviation from normal operation. Minor deficiencies in safety culture.

Table no. 14.1-- Assessment of severity of injury as per International Nuclear and Radiological Event Scale

## 5. Protective Clothing and Basic Instrumentation

In radiological emergencies, personal safety is paramount. Medical responders working in or near contaminated zones must be equipped with proper protective clothing and radiation detection instruments. These safeguard the health of responders while enabling them to conduct assessments and deliver care safely.

### 5.1 Personal Protective Equipment (PPE)

- ❖ Personal protective equipment is designed to protect against external contamination; internal uptake of radioactive particles via inhalation, ingestion, absorption through open wounds and other physical hazards (e.g., debris, fire/heat, or chemicals).
- ❖ The choice of appropriate personal protective equipment (PPE) depends on:
  - Response role and specific tasks

- Risk of contamination
- ❖ Personal Protective Equipment (PPE) plays a critical role during radiological and nuclear emergencies. It **prevents the spread** of contamination by acting as a barrier between radioactive materials and responders. PPE also **protects against aerosolized radioactive particles**, reducing the risk of both external and internal contamination through inhalation, ingestion, or skin absorption. In addition to its protective function, PPE provides **psychological reassurance to responders**, enabling them to operate with greater confidence and safety in high-risk environments.
- ❖ However, PPE cannot protect against exposure from high energy, highly penetrating forms of ionizing radiation associated with most radiation emergencies. In that case, a personal radiation dosimeter may be worn outside the PPE.
- ❖ Proper donning and doffing procedures are essential to avoid contamination. Responders should be trained in how to safely remove PPE without contaminating themselves or others.

## 5.2 PPE Donning (Putting On) Sequence (Before Entering Hot Zone)

- ❖ Before entering the Hot Zone, responders must follow a strict PPE donning sequence to ensure complete protection.
- ❖ The process begins with wearing inner protective clothing, such as a cotton coverall and appropriate undergarments.
- ❖ Next, boots or shoe covers are put on and securely fastened. The responder then dons the chemical protective suit, selecting the appropriate level (A–D) based on the situation (refer table 14.2).
- ❖ Respiratory protection, such as self-contained breathing apparatus (SCBA) or full-face respirator, is worn next, ensuring that the face seal is properly checked.
- ❖ This is followed by donning inner gloves, then outer gloves, making sure they overlap the suit sleeves to maintain a sealed barrier.
- ❖ The hood or helmet is then pulled over to ensure complete coverage of the head and neck.
- ❖ Finally, a buddy\* check is performed by a trained colleague to verify the integrity, fit, and proper sealing of all PPE components before entry into the Hot Zone.

*\* A trained partner supervises donning & doffing to avoid mistakes.*

### **5.3 PPE Decontamination Principles**

- ❖ PPE decontamination must always be carried out within a designated decontamination corridor to prevent secondary contamination of responders or clean areas.
- ❖ The process begins with gross decontamination, which involves removing any visible contamination using water, soap, or absorbent pads.
- ❖ All decontamination activities are performed in the Warm Zone under controlled supervision, ensuring that procedures are systematic and compliant with safety protocols.
- ❖ During the process, run-off water and contaminated materials must be collected in designated containers to prevent environmental spread and ensure proper disposal.
- ❖ Following decontamination, responders undergo radiation level monitoring to confirm clearance before they are allowed to proceed to the Cold Zone.

### **5.4 PPE Doffing Sequence (After Exiting Hot Zone)**

- ❖ PPE doffing must always occur after surface decontamination and within a controlled decontamination corridor to prevent secondary contamination.
- ❖ The process follows a **top-to-bottom removal approach**, ensuring that contaminants are not transferred to clean areas.
- ❖ Doffing begins with removing the outer gloves, followed by carefully lifting off the hood or helmet without touching the skin or hair.
- ❖ The respirator or self-contained breathing apparatus (SCBA) is then removed with the assistance of a trained buddy to maintain safety and prevent accidental exposure.
- ❖ The protective suit is peeled away by rolling it inside-out, minimizing the spread of contaminants.
- ❖ Next, boots or shoe covers are removed in a controlled manner. Inner gloves are taken off last, and responders must immediately wash or decontaminate their hands.
- ❖ After doffing, every responder undergoes a medical check and contamination monitoring to ensure full clearance.

- ❖ All removed PPE is treated strictly as radioactive or CBRN waste and disposed of accordingly.

### 5.5 Levels of PPE

PPE is categorized into different levels of protection based on the nature of hazard, exposure risk, and operational tasks.



Fig.no. – 14. 4 Levels of PPE

PPE Level	Protection Provided	Typical Components	Typical Use / Application
<b>Level A</b> (Maximum Protection)	Highest level of respiratory and skin protection	<ul style="list-style-type: none"> <li>• Fully encapsulated, vapor-tight chemical-resistant suit</li> <li>• Self-contained breathing apparatus (SCBA)</li> <li>• Inner &amp; outer chemical-resistant gloves</li> </ul>	<ul style="list-style-type: none"> <li>• Response to unknown/high-risk radiological or CBRN environments</li> <li>• Radiological Dispersal Device (RDD) or Improvised Nuclear Device (IND) incidents</li> <li>• Initial entry before hazard characterization</li> </ul>

		<ul style="list-style-type: none"> <li>• Chemical-resistant boots</li> </ul>	
<b>Level B</b> (High Respiratory, Moderate Skin Protection)	High respiratory protection, less skin protection than Level A	<ul style="list-style-type: none"> <li>• Non-encapsulating, splash-protective suit</li> <li>• SCBA</li> <li>• Chemical-resistant gloves and boots</li> <li>• Hard hat, face shield (if needed)</li> </ul>	<ul style="list-style-type: none"> <li>• Decontamination operations</li> <li>• Environmental survey teams</li> <li>• Handling radioactive sources in accident sites where vapor hazard is low</li> </ul>
<b>Level C</b> (Moderate Protection)	Protection against known contaminants; requires adequate oxygen levels in the environment	<ul style="list-style-type: none"> <li>• Chemical-resistant coverall/splash suit</li> <li>• Air-purifying respirator (APR) or PAPR with suitable cartridges</li> <li>• Gloves, boots, face shield/goggles</li> </ul>	<ul style="list-style-type: none"> <li>• Triage and medical care in the warm zone</li> <li>• Radiation monitoring and sampling</li> <li>• Support operations where contaminants are known and controlled</li> </ul>
<b>Level D</b> (Minimal Protection)	Minimal protection; provides barrier against nuisance contamination	<ul style="list-style-type: none"> <li>• Standard work uniform (lab coat, coverall)</li> <li>• Gloves</li> <li>• Safety glasses or face shield</li> <li>• Surgical mask (optional)</li> </ul>	<ul style="list-style-type: none"> <li>• Support functions in the cold zone</li> <li>• Administrative/logistic tasks</li> <li>• Public safety enforcement outside contaminated areas</li> </ul>

Table no. 14.2 Levels of PPE

In India, several key institutions contribute to the evaluation and recommendation of personal protective equipment (PPE) for radiological and CBRN emergencies. The Institute of Nuclear Medicine & Allied Sciences (INMAS), Delhi, plays a central role by testing and certifying PPE used for CBRN hazards, including coveralls, masks, and respirators—an expertise that was particularly significant during the COVID-19 response and in radiation emergency preparedness. The Aerial Delivery Research and Development Establishment (ADRDE), Agra, though primarily focused on delivery systems, also contributes to the development and support of protective ensembles designed for personnel operating in hazardous environments. Additionally, both the Atomic Energy Regulatory Board (AERB) and the Bhabha Atomic Research Centre (BARC) provide guidance on selecting appropriate PPE based on factors such as dose rate, contamination characteristics, and the operational responsibilities of responders during radiological incidents. These coordinated efforts help ensure that frontline personnel are equipped with effective and context-appropriate protection. (Refer table 14.3)

Category	Material	Description / Typical Use Case
----------	----------	--------------------------------

<b>Type A PPE</b>	PU coated Nylon/Polyester (material used for parachute)	High-level protection against chemical/radiological threats [from INMAS (Delhi) / ADRDE (Agra)]
<b>Type B PPE</b>	Tri-Laminate (highly breathable material)	Intermediate protection—likely chemical or contamination guards Defence Research Development Establishment, DRDE - Gwalior)
<b>Type C PPE</b>	TPU film laminated poly propylene non-woven fabric 90 GSM (limited breathability)	Standard protection—low-level hazard environments (DRDE - Gwalior)
<b>Two-Piece Coverall</b>	Non-woven, non-laminated breathable coverall (65-70 GSM fabric)	Versatile suit for general use; contamination shielding (Defence Institute of Physiology & Allied Sciences, DIPAS, Delhi)

Table 14.3 Types of PPE (Indian Context)

## 6. Basic Radiation Monitoring Instruments

- ❖ Radiation detection and monitoring equipment should be deployed to map contamination and assess exposure levels. Common tools include handheld Geiger-Müller counters, survey meters, and dosimeters. Use these to establish safe pathways and identify high-risk areas. Medical responders should work with radiation safety officers and technical experts to interpret readings.
- ❖ Responders must also be equipped with radiation detection and monitoring instruments. These tools help identify contaminated zones, assess exposure risk, and ensure safe movement within the response area.
- ❖ Each responder should wear a personal dosimeter, which should be read regularly to ensure that accumulated doses remain within safe limits. Instrument calibration and battery checks must be part of pre-deployment preparation.

Instrument Type	Function	Example Use Case
Geiger-Müller Counter	Detects beta and gamma radiation	Scanning people or objects for contamination
Survey Meter (Ion Chamber)	Measures dose rate over a wide range	Mapping radiation levels at scene
Personal Dosimeter	Tracks individual cumulative exposure	Worn by all responders for dose monitoring
Scintillation Detector	High-sensitivity radiation detection	Rapid survey of large areas

Table No. 14.4-- Essential Radiation Detection Instruments

## 7. Radiation Control on Site

A **command post** should be located in the cold zone, enabling coordination between the incident commander, radiological officer, rescue units, and medical teams. Responders entering the hot zone must adhere to **ALARA principles**: limiting time, maximizing distance, and utilizing shielding.

Zones	Perimeter designation	Activities and guidelines
Inside the inner cordoned area		Only <b>life-saving interventions</b> (Airway opening & massive bleeding control) Shift the patient ASAP not more than 30 minutes.
Inner cordoned area HOT ZONE	Safety perimeter	Area around the site of the accident. Precautions should be taken for preventing exposure and contamination to responders and public
Outer cordoned area WARM ZONE	Security perimeter	Access control, secure zone around the inner cordoned area Waste storage area, Public processing areas, Response Contamination Control Area , Temporary Morgue Area

Table No. 14.5-- Radiation Control on Site

Source: IAEA

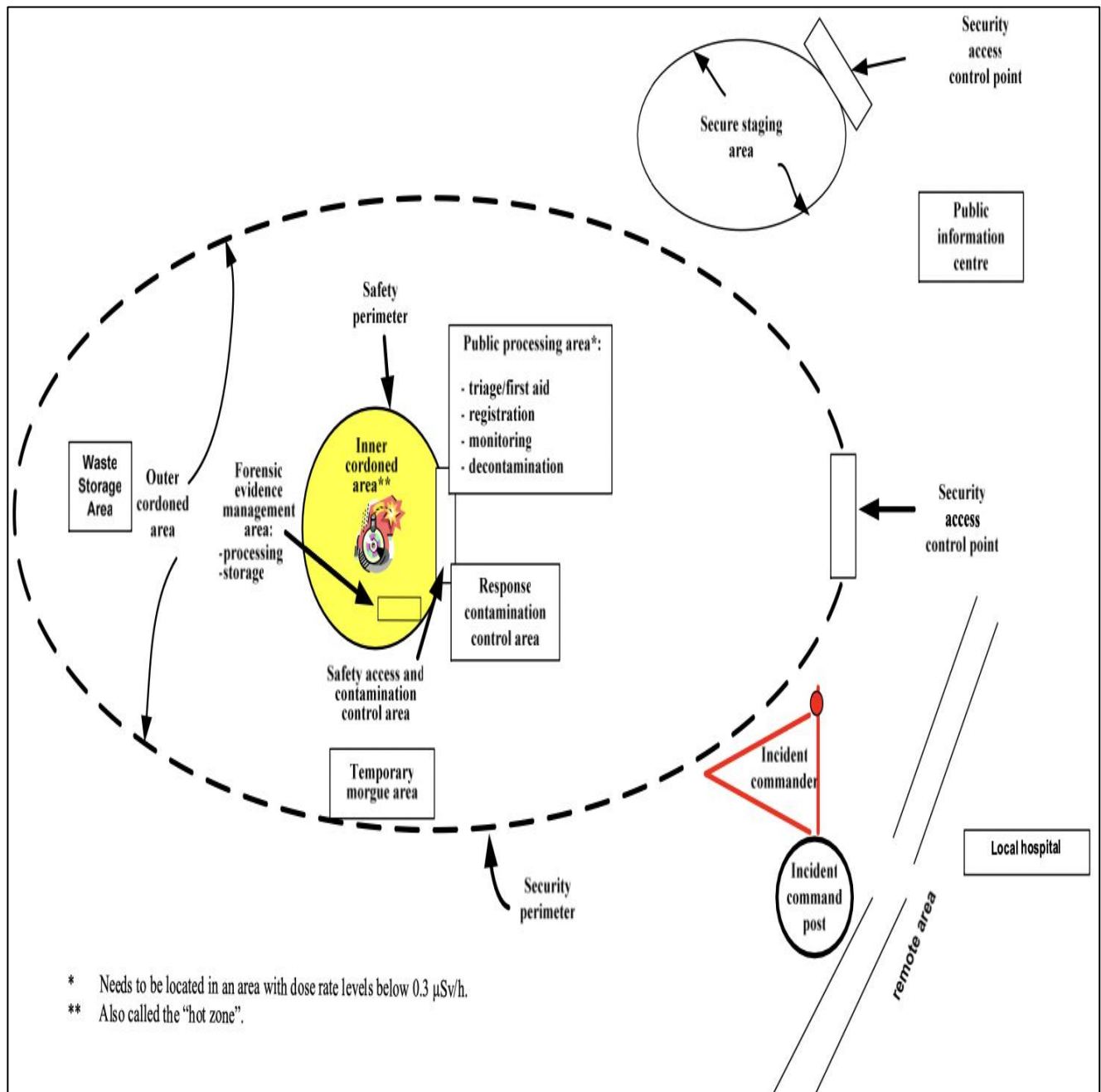


Fig.no. 14.5– Generic layout of response facilities and locations within areas established for a radiological emergency

## 8. Incident Command Centre

Facility	Description	Characteristics
Incident command post (ICP)	Location of the Incident command (IC) and other members of the unified command and support staff.	An area that is secure, safe and convenient for directing operations.
Forensic evidence management area	Location consisting of the forensic evidence processing centre (location for the supervised processing, recording, examination and photography of items and evidence recovered from the scene) and forensic evidence storage area (location for the secure storage of evidence recovered from the scene and for maintenance of the continuity and integrity of evidence).	Located in the inner cordoned area adjacent to the safety access and contamination control area.
Public information centre (PIC)	Location for the coordination of all official information released to the media concerning the emergency.	Located in a secure area in the vicinity of the emergency scene near the ICP with space and infrastructure to support the media briefings.
Public processing area	Location consisting of the triage/first aid area, registration area, public monitoring / decontamination area. At this location the following tasks are performed: - processing and registering the public evacuated from the inner cordoned area; - medical triage, first aid and preparation of victims for transport; and - monitoring and decontamination of the public evacuated from the inner cordoned area.	Located within the outer cordoned area with access for medical transport. Ambient dose rates in the area need to be at levels close to background levels.
Local hospital	Hospital to provide the first treatment to exposed and/or contaminated people.	Located close to the scene of an emergency and that has been contacted to prepare to receive exposed and/or contaminated victims.
Response contamination control area	Location for the control of contamination from response personnel entering and leaving the inner cordoned area.	Located at the boundary of the inner cordoned area and away from the public processing area

Staging area	Location used to collect and organize additional resources as they arrive in the vicinity of the emergency.	Located where it will not interfere with other ongoing response actions and has been searched and secured
Temporary morgue area	Location for the dignified storage of deceased victims whose bodies may be contaminated or have not been released by the FEMT.	May be located in a tent or existing facility that is secured within the outer cordoned area away from the view of the general public.
Waste storage area	Location where potentially contaminated items (e.g. clothing) are stored.	Located within the outer cordoned area that is secured and preferably in a structure to prevent the spread of contamination (e.g. by wind or rain).

Table No. 14.6 -- Command Description and Characteristics (adapted from IAEA)

## 8.1 Initial Communication

Figure 14.6 illustrates a streamlined incident command and communication structure during a radiological nuclear emergency.

- ❖ The **Response Initiator** triggers the emergency response and communicates directly with both the Incident Commander at the Incident Command Post (ICP) and the National Emergency Operations Center (EOC).
- ❖ The **Incident Commander** centrally coordinates on-site response operations, managing key emergency services including:
  - Fire Brigade
  - Emergency Medical Service (EMS)
  - Law Enforcement/Security Teams
- ❖ Simultaneously, the National EOC provides expert support through radiological assessors and other national-level resources. It maintains communication with both the Incident Commander and the Response Initiator.

- ❖ The communication lines (dashed) and management control lines (solid) ensure that decision-making and situational awareness are synchronized across all levels.
- ❖ This structure ensures a clear chain of command, effective multi-agency coordination, and timely radiological risk assessment and response.

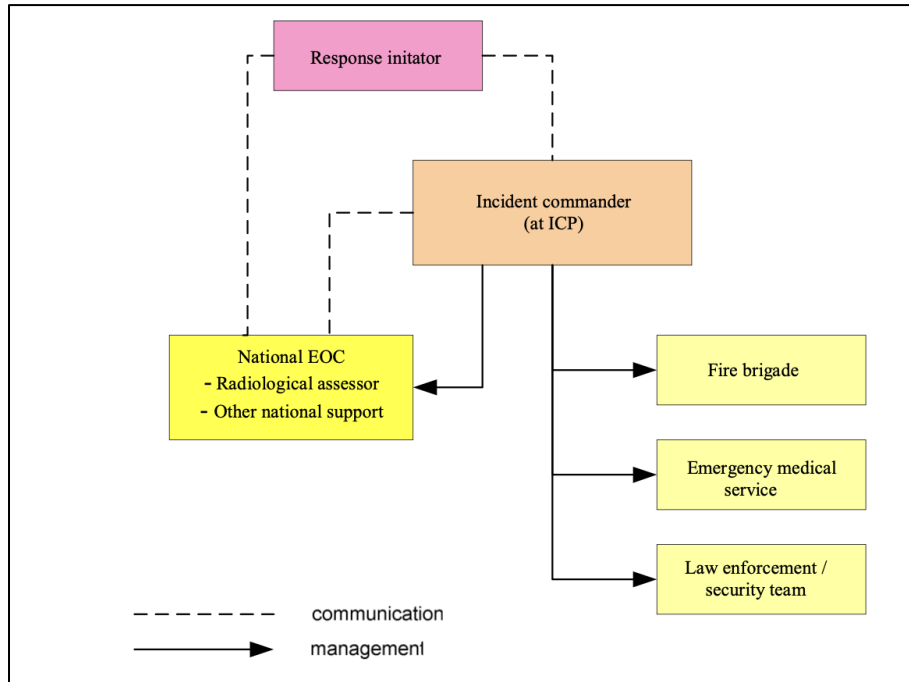


Fig. no. 14.6-- Flow chart representation of Incident Command Centre- Initial Communication

## 8.2 Communication in a few hours

Figure 14.7 outlines a comprehensive multi-tiered response framework for radiological emergencies, emphasizing coordination across command, planning, operational, and national support functions.

- ❖ At the core is the Incident Commander (ICP), supported by the Command Group and Public Information Officer/Team, ensuring central oversight and communication.
- ❖ The Planning Function includes a Resource Coordinator (at staging area) and a 24-hour Planning Coordinator, responsible for logistics and sustained response strategy.

❖ The Operation Function is directed by an optional On-scene Controller, coordinating critical services like:

- Fire brigade
- Emergency medical services
- Hospitals
- Law enforcement/security
- Forensic teams
- First responder monitoring

❖ The National Emergency Operations Center (EOC) provides radiological assessment and national-level support, linking planning and command structures to national expertise.

❖ This structure ensures efficient information flow, resource deployment and operational synergy, critical for minimizing health impacts during radiation emergencies.

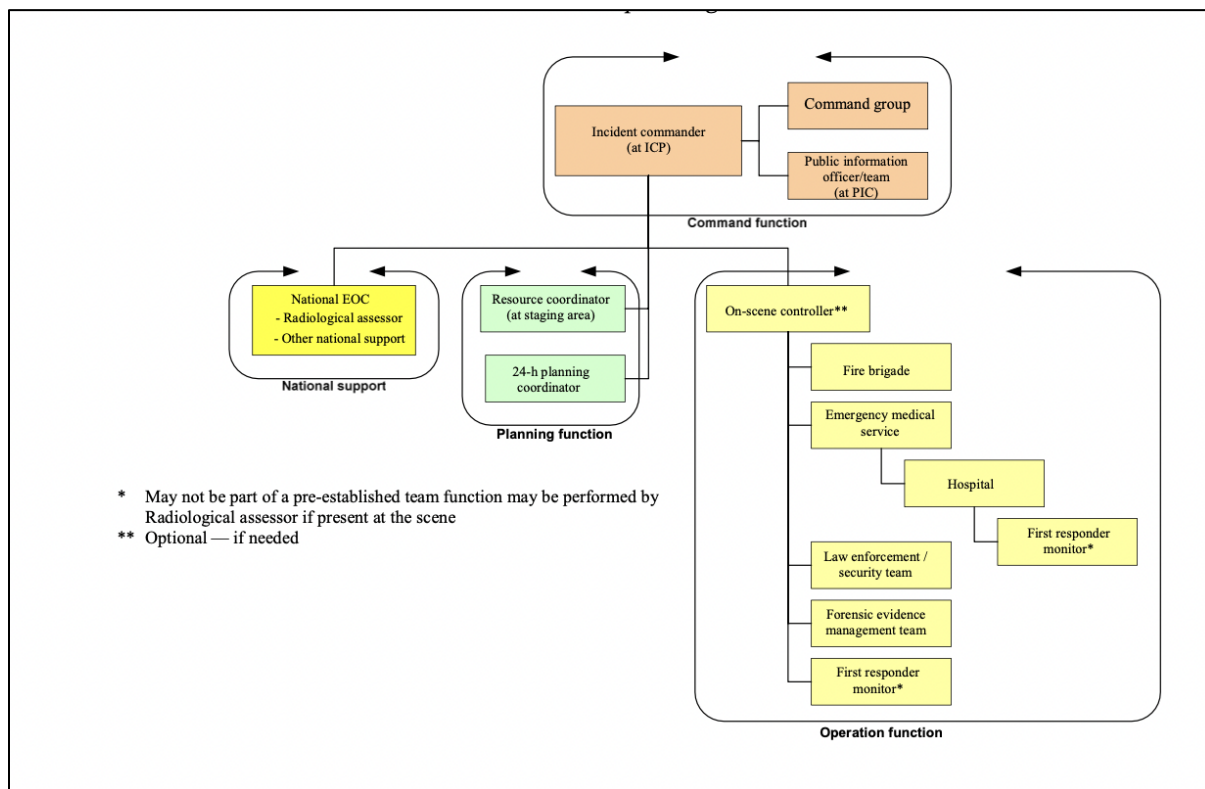


Fig. no. 14.7-- Flow chart representation of Incident Command Centre- Communication in a few hours

## **8. Establishing a reception center (RC)**

In the event of a radiological emergency, the Reception Centre (RC) plays a pivotal role in managing potentially exposed individuals. It acts as the initial interface between the affected population and the emergency response system. Strategically located at a safe distance from the epi-centre, and outside the Hot and Warm Zones, the RC ensures early detection of contamination, initial triage, psychosocial support, and streamlined referral to medical or decontamination units.

### **8.1 Functions of RC:**

- ❖ The Reception Centre (RC) plays a vital role during radiological, chemical, or biological emergencies by serving as the first organized point of contact for affected individuals.
- ❖ Its functions include screening and monitoring people for potential contamination, followed by registration and triage to categorize patients based on urgency and exposure status.
- ❖ The RC is also responsible for providing immediate lifesaving interventions, such as airway management, bleeding control, and initial stabilization.
- ❖ In addition, the centre conducts decontamination procedures, including dry or wet decontamination and the removal of contaminated clothing.
- ❖ Beyond medical functions, the RC offers psychosocial support and timely information, helping reduce anxiety among affected populations.
- ❖ It is staffed by trained responders wearing appropriate PPE and supported by coordinated medical, security, and administrative teams, ensuring a safe and efficient response.

### **8.2 Casualty Receiving Centre (CRC)**

- ❖ The Casualty Receiving Centre (CRC) acts as the medical extension of the Reception Centre (RC) and is typically located further downstream, either within a hospital setting or at a designated medical post.
- ❖ It serves as the primary point for definitive medical care once individuals have undergone initial decontamination at the RC.

- ❖ The CRC carries out secondary triage, categorizing patients based on the severity of injuries and extent of contamination.
- ❖ It provides specialized medical treatment, including chelation therapy, administration of antidotes, supportive care, and management of Acute Radiation Syndrome (ARS).
- ❖ In addition, the CRC offers psychological first aid and facilitates long-term medical monitoring and follow-up.
- ❖ The center operates in close coordination with hospital emergency departments and other secondary or tertiary medical facilities to ensure seamless, comprehensive patient management.

### **8.3 Secondary-level RN Medical Management Centers**

- ❖ Secondary-level Radiological and Nuclear (RN) Medical Management Centers are established within district or zonal hospitals designated for disaster and emergency response. These centers are equipped to manage moderate to severe CBRN casualties referred from Reception Centers (RC) or Casualty Receiving Centers (CRC).
- ❖ Their capabilities include isolation and containment facilities, such as negative-pressure rooms for biological threats, and dedicated decontamination units for both ambulatory and non-ambulatory patients.
- ❖ They maintain stockpiles of critical medical countermeasures, including antidotes, decorporation agents, potassium iodide (KI) tablets, and essential supportive medications.
- ❖ The centers also provide advanced laboratory support, such as bioassay analysis, cytogenetic testing, toxicology services, and radiological monitoring.
- ❖ Staffing includes multidisciplinary specialists—radiation medicine experts, toxicologists, microbiologists, and psychiatrists—ensuring comprehensive casualty care.
- ❖ Functionally, these centers serve as a vital link between field-level response units (RC/CRC) and tertiary-level apex institutions such as INMAS, AIIMS, and DRDO-designated facilities, enabling a coordinated, tiered medical response to RN emergencies.

### **8.4 Other Tertiary level RN center / specialized referral centers (if needed).**

- ❖ Other tertiary-level Radiological and Nuclear (RN) centers serve as national-level specialized referral institutions with advanced capabilities for managing complex RN emergencies.
- ❖ These centers possess expertise in high-end diagnostics, including cytogenetic bio-dosimetry, whole-body counting, organ-specific dosimetry, and advanced imaging for internal contamination assessment.
- ❖ They offer comprehensive decontamination facilities, including specialized isolation units, controlled radiological treatment areas, and infrastructure for managing high-activity contamination.
- ❖ These institutions also provide definitive medical management, such as administration of rare decorporation agents, stem-cell support therapies for severe Acute Radiation Syndrome, and long-term surveillance for radiation-induced injuries.
- ❖ Staffed by experts in radiation medicine, nuclear toxicology, medical physics, and emergency medicine, these centers function as the apex referral points in the national RN medical response chain.
- ❖ They support lower-tier facilities through telemedicine, expert consultation, training, research, and deployment of rapid response teams when required, ensuring coordinated national capacity for handling large-scale or highly complex RN incidents.

### **Flow of Patients**

**Incident Site → Reception Centre (RC) → Casualty Receiving Centre (CRC) → Secondary-level CBRN Medical Management Centre → Other Tertiary level RN centre / specialized referral centers (if needed).**

## **9. Handling contaminated patients**

Handling contaminated patients in a radiological emergency requires simultaneous application of medical and radiological safety protocols. A coordinated multi-disciplinary response is essential to stabilize patients while containing contamination and preventing secondary exposure among responders.

### **9.1 General principles of management**

- ❖ Management begins with immediate lifesaving actions (Airway opening and massive bleeding control), as decontamination must never delay resuscitation.
- ❖ Standard triage systems should be followed, with prioritization based on physiological instability rather than contamination levels.
- ❖ Radiation safety principles—time, distance, and shielding—must guide all patient interactions.
- ❖ Preventing spread of contamination is equally essential; this is achieved by dividing the treatment area into designated clean and dirty zones, ensuring staff use appropriate PPE, performing routine contamination checks, and maintaining strict workflows to avoid cross-contamination.

## 9.2 Special considerations

Certain patient groups require adapted approaches such as:

- ❖ **Pediatric patients** may experience fear and difficulty cooperating; they may need assistance with removing contaminated clothing and continuous reassurance from trained responders.
- ❖ **Pregnant women** require immediate stabilization like any other casualty, but additional fetal monitoring should be done, if feasible.
- ❖ **Non-ambulatory patients** cannot undergo standard decontamination procedures and should be decontaminated on stretchers or on roller beds that minimize movement while ensuring effective cleaning.

## 9.3 Setting up a decontamination area

- ❖ The establishment of a decontamination area is typically the responsibility of NDRF, police, or designated first responders. The area should be located upwind and uphill, ideally at least 300 yards from the contamination source to reduce exposure from airborne particulates.
- ❖ A clearly demarcated system of Hot, Warm, and Cold Zones must be established, with the hot line serving as the critical boundary to prevent contamination spread.
- ❖ Separate lanes or areas should be designated for ambulatory and non-ambulatory patients to ensure efficient flow and minimize bottlenecks.

- ❖ Controlled access protocols must be strictly enforced so that only personnel wearing appropriate PPE and trained in contamination control are allowed inside the decontamination area.
- ❖ Proper drainage, waste collection, radiation monitoring stations, and backup water supply should be in place to maintain safe and effective operations.

## **10. Guidance for medical teams at Emergency Room (ER)**

In radiological emergencies, some individuals may leave the scene prematurely and present directly to ERs, bypassing formal triage and reception centers. These cases pose risks of contamination spread and delayed medical stabilization.

### **10.1 Key Steps for ER Medical Teams**

#### **10.1.1 Initial Safety Measures**

- ❖ In radiological emergencies, all walk-in casualties should be assumed to be potentially contaminated until proven otherwise. Emergency Room (ER) staff must don basic personal protective equipment (PPE), including gloves, gowns, masks, and eye protection, to minimize risk of secondary exposure.
- ❖ Triage and any preliminary decontamination should be performed outside the main ER, ideally in an open or designated area, to prevent contamination of hospital facilities.
- ❖ Patients should be isolated in a designated area away from general ER traffic, ensuring safety for other patients and staff.
- ❖ Finally, the hospital's Radiation Safety Officer (RSO) or Emergency Response Officer should be notified immediately to guide further monitoring, contamination assessment, and coordination with higher-level medical or disaster response teams.

#### **10.1.2 Triage & Identification**

- ❖ Once the patient is secured in a safe area, ER teams must perform rapid triage and identification.

- ❖ The primary focus is on life-threatening conditions, using the ABC approach (Airway, Breathing, Circulation).
- ❖ At the same time, responders should obtain a brief exposure history, including the patient's location during the incident, time since exposure, and onset of any symptoms such as nausea, vomiting, dizziness, or burns.
- ❖ All relevant details—including patient name, time of arrival, and suspected contamination level—should be recorded and labeled clearly to ensure proper tracking, monitoring, and subsequent medical care.
- ❖ This process ensures that critical patients receive immediate attention while maintaining contamination control and documentation for later follow-up.

### **10.1.3 Contamination Control**

- ❖ Contamination control is a critical step in managing self-evacuated radiological casualties in the ER.
- ❖ The patient's outer clothing should be removed immediately, as this alone can eliminate up to 90% of surface contamination.
- ❖ All personal belongings must be bagged and clearly labeled as "Radioactive—Handle with Care" to prevent accidental spread.
- ❖ If radiation monitoring equipment is available, responders should perform a wipe-test or detector scan to assess residual contamination; otherwise, visual inspection for dust, powder, or suspicious residues should be conducted.
- ❖ Basic decontamination of exposed skin can be performed using lukewarm water and mild soap, avoiding abrasive scrubbing that could damage the skin.
- ❖ Throughout this process, responders should remain within designated zones and use appropriate PPE to protect themselves and maintain a controlled environment, preventing secondary contamination of ER staff, infrastructure, and other patients.

### **10.1.4 Medical Stabilization**

- ❖ After contamination control, the priority remains stabilizing life-threatening conditions.

- ❖ Emergency interventions include managing airway obstruction, controlling massive bleeding, treating burns, and addressing trauma.
- ❖ Symptomatic care should also be provided, such as anti-emetics for nausea and vomiting, analgesics for pain, and appropriate wound care.
- ❖ Suspected radiation burns should initially be treated as thermal burns until a detailed assessment by radiation medicine specialists is available.
- ❖ The guiding principle is to stabilize the patient first, even if full decontamination is not yet complete, ensuring that immediate threats to life are addressed before moving on to definitive radiological management or transfer to specialized facilities.

#### **10.1.5 Coordination & Escalation**

- ❖ Effective coordination is essential for managing radiological casualties presenting to the ER.
- ❖ The hospital command center, local administration, and relevant emergency response agencies such as NDRF or SDRF should be notified immediately to ensure timely support and guidance.
- ❖ ER teams should prepare the patient for transfer to a Casualty Receiving Centre (CRC) or a secondary-level CBRN/RN medical management facility once stabilization is achieved.
- ❖ Detailed documentation must be maintained throughout, including the patient's condition on arrival, all contamination control and decontamination steps, exposure history, and treatment provided.
- ❖ Proper coordination ensures that the patient receives continuity of care, while minimizing risk to hospital staff, infrastructure, and other patients.

#### **10.1.6 Hospital & Staff Protection**

- ❖ Protecting hospital personnel and infrastructure is a key component of ER management during radiological emergencies.
- ❖ Entry and exit points for suspected contaminated patients should be restricted and clearly marked to prevent accidental exposure to other patients or staff.

- ❖ Dedicated isolation and decontamination zones should be used to contain contamination within controlled areas.
- ❖ ER personnel must wear appropriate PPE, and their exposure should be monitored regularly using dosimeters or contamination surveys.
- ❖ Equipment and surfaces that come into contact with contaminated patients must be decontaminated according to established protocols. Maintaining strict adherence to these measures ensures the safety of healthcare providers while allowing critical medical interventions to continue without interruption.

Points to note:

- **Do not refuse treatment** to self-evacuated casualties.
- **Prioritize safety** of responders, other patients, and hospital facilities.
- **Stabilize first, decontaminate as soon as feasible, notify authorities immediately.**

#### Box 14.1 Summary

### 11. Transport of contaminated patients

Transporting radiologically contaminated patients to a medical facility requires careful coordination to ensure both patient stabilization and containment of radioactive materials. Before transport, the patient must be medically stabilized, addressing life-threatening conditions such as airway obstruction, bleeding, burns, or trauma.

❖ **Treat Any Life-Threatening Injuries First**

- Immediate stabilization of airway, breathing, and circulation (ABCs) is the top priority, regardless of contamination.

❖ **Remove External Clothing and Perform Decontamination**

- Take off all outer garments carefully, as this may remove up to 90% of contamination.
- Wash the patient thoroughly with soap and lukewarm water to reduce external radioactive particles.

❖ **Cover Open Wounds**

- Protect open wounds with plastic or waterproof dressings to prevent internal contamination or spread of radionuclides (as shown in figure 14.7)

❖ **Transport Patient Safely**

- After decontamination and wound management, transport the patient with appropriate monitoring and protective measures in place.
- Place 2 sheets/blankets before placing the contaminated patient (as shown in figure 14.8).
- Fold the edges of the 2 layers of sheets over the patient while maintaining access to the airway and adequate visual surveillance (as shown in figure 14.9).
- Place at least one layer of covering on the gurney before loading the litter onto the gurney.
- Close all compartments of the transport vehicle before starting transport.
- Use disposable equipment when possible.
- Check for contamination if needed decontaminate vehicle.

Box 14.2 – Transportation of Contaminated Patients



Fig. no. 14.8 -- Wound cover up



Fig. no.14.9 – Preparing patient for transport



Fig. no.14.10 – Preparing patient for transport

## 12. Documentation and Tracking

- ❖ Accurate documentation and patient tracking are critical components of radiological emergency management.
- ❖ Each patient should be issued a **unique identification bracelet and corresponding barcode sheets** to ensure precise tracking throughout the care pathway.
- ❖ A **radiation exposure logbook** should be maintained to record contamination levels, decontamination steps, and any dosimeter readings, providing a clear record for medical, legal, and regulatory purposes.
- ❖ Documentation must also include **informed consent for treatment** and disclosures regarding potential contamination risks, ensuring ethical and legal compliance.
- ❖ Additionally, all referral records should be linked to hospital triage and medical records to maintain continuity of care as patients move between Reception Centres, Casualty Receiving Centres, secondary-level RN facilities, and tertiary referral centres.
- ❖ This systematic tracking ensures patient safety, accountability, and efficient management of resources during mass-casualty radiological events.

### Take Home Message:

- ❖ Early detection of radiation signs is crucial to initiate a timely response.
- ❖ Scene assessment and control zones (Hot, Warm, Cold) reduce risk and confusion.
- ❖ PPE and monitoring devices are essential for responder safety.
- ❖ Reception Centers (RCs) streamline triage, screening, and referral.
- ❖ Decontamination must be done without delaying critical medical care.
- ❖ Decontamination for all possible patients is conducted in the Warm zone
- ❖ Transport contaminated patients if decontamination is not possible
- ❖ Clear roles, documentation, and access logs prevent contamination spread.
- ❖ Coordination among medical, technical, and command teams is vital.
- ❖ Regular drills and pre-incident training ensure operational readiness.
- ❖ Risk communication helps manage public fear and misinformation.

## References (Adapted from)

- IAEA (2006)"Manual for First Responders to a Radiological Emergency."
- IAEA (2008) International Nuclear and Radiological Event Scale (INES) User's Manual.
- United States Nuclear Regulatory Commission (NRC). "Radiation Protection and Emergency Preparedness." <https://www.nrc.gov>
- WHO "Health Effects of Radiation." <https://www.who.int>
- Federal Emergency Management Agency (FEMA). "Radiological Emergency Preparedness Manual." <https://www.fema.gov>
- U.S. Department of Health and Human Services. "Radiological and Nuclear Disaster Response and Recovery." 2021.
- Bhabha Atomic Research Centre (BARC), India. "Radiation Detection Instruments." <https://www.barc.gov.in/technologies/radinst.html>
- Defence Research and Development Organisation (DRDO), India. <https://drdo.gov.in>
- NDMA. Guidelines for the Management of CBRN Emergencies in India. <https://ndma.gov.in/CBRN>
- AERB. Emergency Planning in Nuclear Facilities: Safety Guide. <https://aerb.gov.in>
- Sharma, R. et al. (2022). "Radiation Protection in Indian Emergency Response Scenarios." Indian Journal of Radiological Protection.
- Suri, J.C. et al. (2020). "Indian Medical Response Framework for Radiological Incidents." Journal of Disaster Medicine in India.
- Ministry of Home Affairs. Standard Operating Procedures for Disaster Response, GoI, 2019.
- WHO. Manual for Public Health Response to Radiological Emergencies. 2009.
- CDC. Radiation Emergency Medical Management (REMM). <https://www.remm.nlm.gov>

- AERB. Guidelines on Medical Management in Radiological Incidents. <https://aerb.gov.in>
- BARC. Emergency Decontamination and Response Kits. <https://barc.gov.in>
- WHO (2020). Radiological and Nuclear Emergencies: Medical Response Manual.
- AERB (2021). Guidelines for Radiation Emergency Preparedness.
- BARC (2018). Preparedness for Nuclear and Radiological Emergencies.
- DRDO-INMAS/ADRDE (2020). CBRN Medical Preparedness Guidelines.
- NDMA. Hospital Preparedness for Chemical and Radiological Emergencies. <https://ndma.gov.in>
- DRDO-INMAS. Field Guide for Handling Radiological Casualties, 2021.
- OSHA Best Practices for Protecting EMS Responders during Treatment and Transport of Victims of Hazardous Substance Releases. (OSHA 3370-11. OSHA, 2009, Appendix M, p. 78)
- Lerner EB, Cone DC, Weinstein ES, Schwartz RB, Coule PL, Cronin M, Wedmore IS, Bulger EM, Mulligan DA, Swinton RE, Sasser SM, Shah UA, Weireter LJ Jr, Sanddal TL, Lairet J, Markenson D, Romig L, Lord G, Salomone J, O'Connor R, Hunt RC. Mass casualty triage: an evaluation of the science and refinement of a national guideline. *Disaster Med Public Health Prep.* 2011 Jun;5(2):129-37. [PubMed Citation]
- Manual for First Responders to a Radiological Emergency, page 12, (PDF - 2.2 MB) (CTIF, IAEA, PAHO, WHO, October 2006) and Generic Procedures for Medical Response during a Nuclear or Radiological Emergency, Section C, Figure C1, page 38, (PDF - 2,224 KB) (IAEA, WHO, April 2005) [http://remm.hhs.gov/zones\\_IAEA.htm](http://remm.hhs.gov/zones_IAEA.htm)
- Coleman CN, Weinstock DM, Casagrande R, et al. Triage and Treatment Tools for Use in a Scarce Resources-Crisis Standards of Care Setting After a Nuclear Detonation. *Disaster Medicine and Public Health Preparedness.* 2011;5(S1): S111-S121. doi:10.1001/dmp.2011.22
- Types of PPE table (14.2 and 14.3) - <https://www.drdo.gov.in/drdo/index.php/ppe> And <https://www.indiascienceandtechnology.gov.in/academiaindustrypartnerships/ppe-type-4?>

- Atomic Energy Regulatory Board (AERB). (2009). Emergency preparedness for nuclear and radiological facilities in India. Mumbai: AERB.
- Bhabha Atomic Research Centre (BARC). (2011). Radiological safety and emergency response guidelines. Mumbai: BARC.
- IAEA (2006). Manual for first responders to a radiological emergency.
- IAEA (2015). Preparedness and response for a nuclear or radiological emergency (IAEA Safety Standards Series No. GSR Part 7)
- WHO (2005). Radiological terrorism: Emergency medical preparedness and response.
- WHO. Manual for First Responders to a Radiological Emergency, 2009.
- AERB. Emergency Preparedness and Response Plans for Nuclear and Radiological Facilities in India, 2014.
- BARC/INMAS Guidelines on Medical Management of CBRN Emergencies (DRDO Publications).
- Images:
  - Fig.no. 14.1 (AERB)
  - Fig.no. 14.2 (IAEA)
  - Fig.no. 14.3 [IAEA INES User Manual (2008)]
  - Fig.no. 14.4 (<https://www.pinterest.com/pin/415527503111918468/>)
  - Fig.no. 14.5 (IAEA, WHO, April 2005)
  - Fig.no. 14.6,14.7 (IAEA 2006)
  - Fig.no. 14.8,14.9,14.10 (cases)

### **Suggested Reading**

- NDMA. Guidelines for the Management of CBRN Emergencies in India. <https://ndma.gov.in/CBRN>
- IAEA (2006) Manual for First Responders to a Radiological Emergency (EPR-First Responders) <https://www.iaea.org/publications/7606/manual-for-first-responders-to-a-radiological-emergency>
- Manual for First Responders to a Radiological Emergency, page 12, (PDF - 2.2 MB) (CTIF, IAEA, PAHO, WHO, October 2006) and Generic Procedures for Medical Response during a Nuclear

or Radiological Emergency, Section C, Figure C1, page 38, (PDF - 2,224 KB) (IAEA, WHO, April 2005) [http://remm.hhs.gov/zones\\_IAEA.htm](http://remm.hhs.gov/zones_IAEA.htm)

## Chapter 15

### On-site activities: Triage in Radiological and nuclear(RN) Emergencies

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand how to triage in various zones in RN emergencies
- Understand what are the equipment required for RN triage

#### 1. Introduction

**Triage** is a system of sorting victims to determine who needs immediate care, who can wait, and who is beyond help. It helps allocate limited medical resources efficiently. Triage helps identify patients with life-threatening or limb-threatening injuries. The first step in radiological and nuclear emergencies triage is to screen for life-threatening emergencies. A unique challenge in radiological and nuclear emergencies is to screen for contaminated patients

##### 1.1 Definition of Triage

“Triage is the process of sorting casualties to prioritize medical treatment and evacuation based on the severity of injuries and prognosis, especially under resource-limited conditions.” (IAEA, 2006)

#### 2. Why Triage in radiological and nuclear Emergencies

Triage in radiological and nuclear emergencies is a critical component of emergency response due to the sudden surge of patients and the often limited availability of medical resources. It allows healthcare providers to quickly identify critical patients i.e. individuals with life-threatening or limb-threatening injuries, ensuring that those who need immediate care receive it without delay. Triage also promotes equitable distribution of patients across available healthcare facilities,

preventing any single center from becoming overwhelmed. Additionally, by separating patients with minor injuries early in the process, triage optimizes the use of resources and enhances the overall efficiency of the healthcare system, allowing medical personnel to focus on those in greatest need.

### **2.1 Steps of triage in radiological and nuclear emergencies:**

- Step 1 Triage-Mass Casualty triage as per severity of trauma or burns
- Step 2 Triage-Combined radiation plus severity of injury or burns triage

### **3. Zones in Radiological and Nuclear Emergencies**

Radiological and nuclear incidents are managed by dividing the affected area into distinct zones according to contamination levels and associated risk.

#### **3.1 Hot Zone**

- ❖ The Hot Zone encompasses the immediate area of the disaster, where contamination and radiation levels are highest.
- ❖ Only first responders equipped with Level A personal protective equipment (PPE) are permitted entry.
- ❖ Interventions in this zone are limited to essential, life-saving measures such as airway management, control of massive bleeding, and rapid patient evacuation.

#### **3.2 Warm Zone: Triage and Decontamination**

- ❖ The Warm Zone is established around the periphery of the Hot Zone and serves as the location for triage and initial decontamination.
- ❖ Triage is conducted at the entrance of this zone to assess the severity of injuries. Patients requiring immediate life-saving interventions are prioritized for direct transfer to the Cold Zone, ensuring that decontamination does not delay critical care.
- ❖ Removal of clothing can eliminate more than 90% of surface contamination, and decontamination can be performed using showers or dry methods.
- ❖ First responders in Level A or B PPE conduct this process.

- ❖ Standard triage systems such as START (Simple Triage and Rapid Treatment), SALT (Sort, Assess, Lifesaving Interventions, Treatment/Transport), or RN-adapted protocols are used to categorize patients as Red, Yellow, Green, or Black based on urgency.

### 3.3 Cold Zone: Definitive Care

- ❖ The Cold Zone lies outside the Warm Zone and is considered safe from contamination. Step 2 triage is performed here, typically at the Casualty Reception Centre (CRC) or Emergency Room (ER).
- ❖ Hospital staff, equipped with appropriate PPE, provide care for decontaminated patients. Interventions include definitive care such as advanced stabilization, monitoring, and ongoing treatment.
- ❖ Psychological first aid is also provided to individuals affected by the incident.
- ❖ Additionally, the Cold Zone serves as the point for preparing patients for further transport to higher-level facilities if needed.

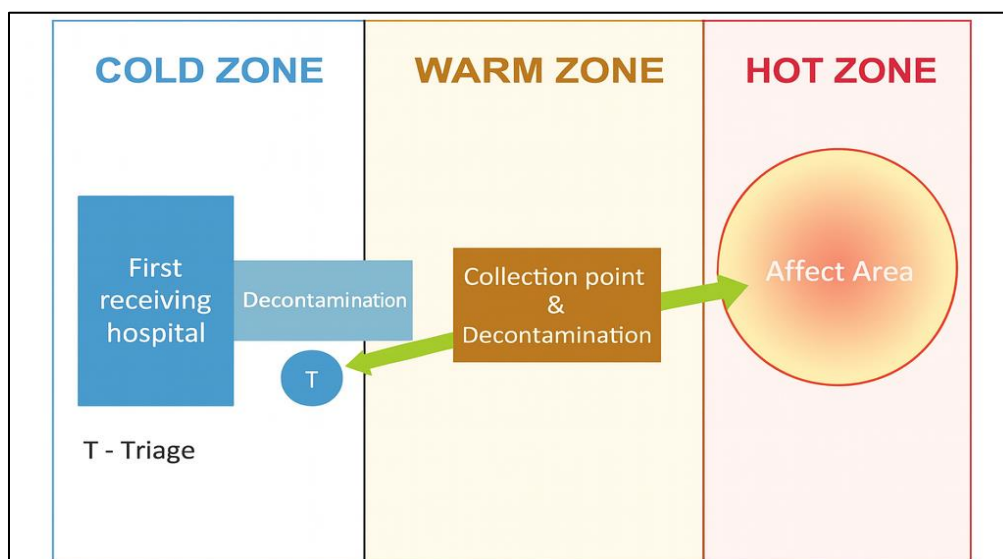


Fig.no.15.1 – Zones in radiological and nuclear emergencies

## 4. Patient Flow in Radiological and Nuclear Emergency

The patient flow during a radiological or nuclear emergency follows a structured, zoned approach to ensure contamination control, responder safety, and efficient use of medical resources. (refer figure 15.2)

#### 4.1 Hot Zone (Contaminated Zone)

In the Hot Zone, immediate life-saving interventions are performed as required. Once stabilized, patients are evacuated to the Warm Zone for triage and decontamination.

#### 4.2 Warm Zone (Contamination Reduction Zone)

Step 1 Triage is conducted in the Warm Zone to classify patients according to the urgency of their injuries and contamination status. Critical patients requiring life-saving interventions, categorized as **Red**, may be transferred immediately without full decontamination. Stable patients, classified as **Yellow or Green**, undergo decontamination before further treatment. Deceased or expectant patients are labeled **Black** and are not moved to the Cold Zone.

#### 4.3 Cold Zone (Clean Treatment Zone)

Step 2 Triage takes place in the Cold Zone, where patients are reassessed for injury severity and residual contamination. Following this, patients are directed to definitive care facilities for advanced treatment, stabilization, monitoring, and ongoing medical management.

This zoned patient flow ensures that contaminated and non-contaminated areas are effectively separated, first responders remain protected, and medical resources are allocated efficiently during mass casualty radiological and nuclear incidents.

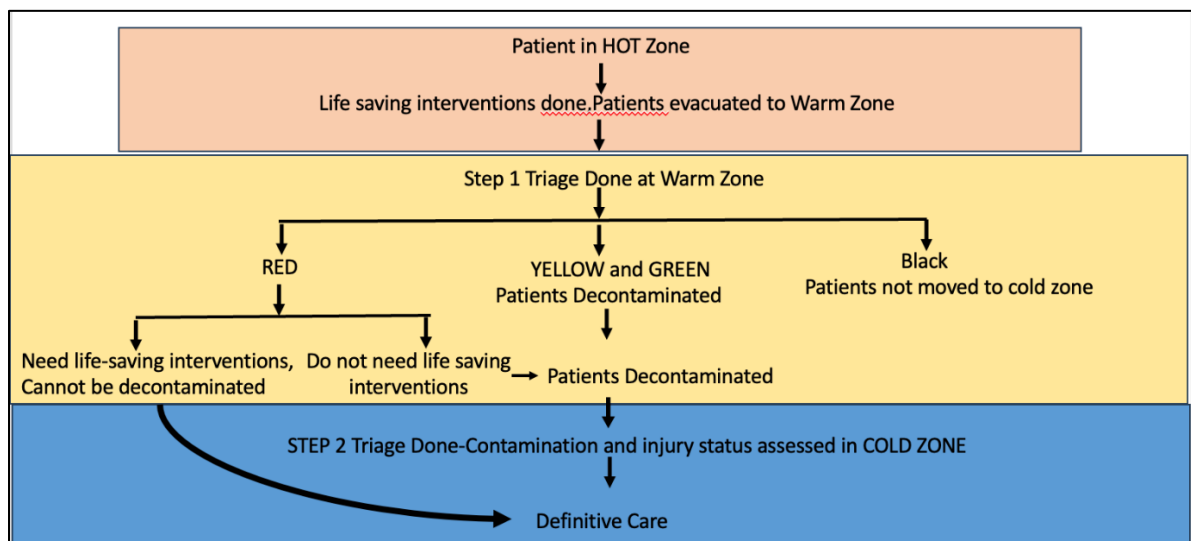


Fig.no. 15.2 – Flowchart depicting patient flow in RN emergency

## 5. Classification under Different Triage Systems

### 5.1 Step 1 triage in RN emergencies

- ❖ Step 1 Triage in RN emergencies is an initial, rapid assessment conducted primarily in the Warm Zone and is largely based on clinical evaluation. It involves a quick visual and physical assessment of patients to identify contamination symptoms and prioritize care based on visible injuries, level of consciousness, respiratory effort, and other vital signs. Multiple triage systems are employed to categorize patients efficiently and ensure optimal use of limited medical resources. Commonly used systems include START for adults (figure 15.3) and Jump START for pediatric patients. Other widely applied systems include SALT (Sort, Assess, Lifesaving Interventions, Treatment/Transport) for all-hazard scenarios, SAVE (Secondary Assessment of Victim Endpoint) for severely resource-limited situations, MASS (Move, Assess, Sort, Send) for field triage, and STM (Sort-Triage-Manage) as a decision-making tool in disaster settings.
- ❖ Patients are typically classified into the following categories:
  - Immediate (Priority 1): Life-threatening injuries requiring urgent intervention.
  - Urgent (Priority 2): Serious injuries that are not immediately life-threatening.
  - Delayed (Priority 3): Non-urgent or minor injuries.
  - Expectant: Patients unlikely to survive even with care (often coded Black or Blue).
  - Dead: No signs of life.

This structured approach ensures that care and resources are directed to those most likely to benefit, maximizing survival during mass casualty RN incidents.

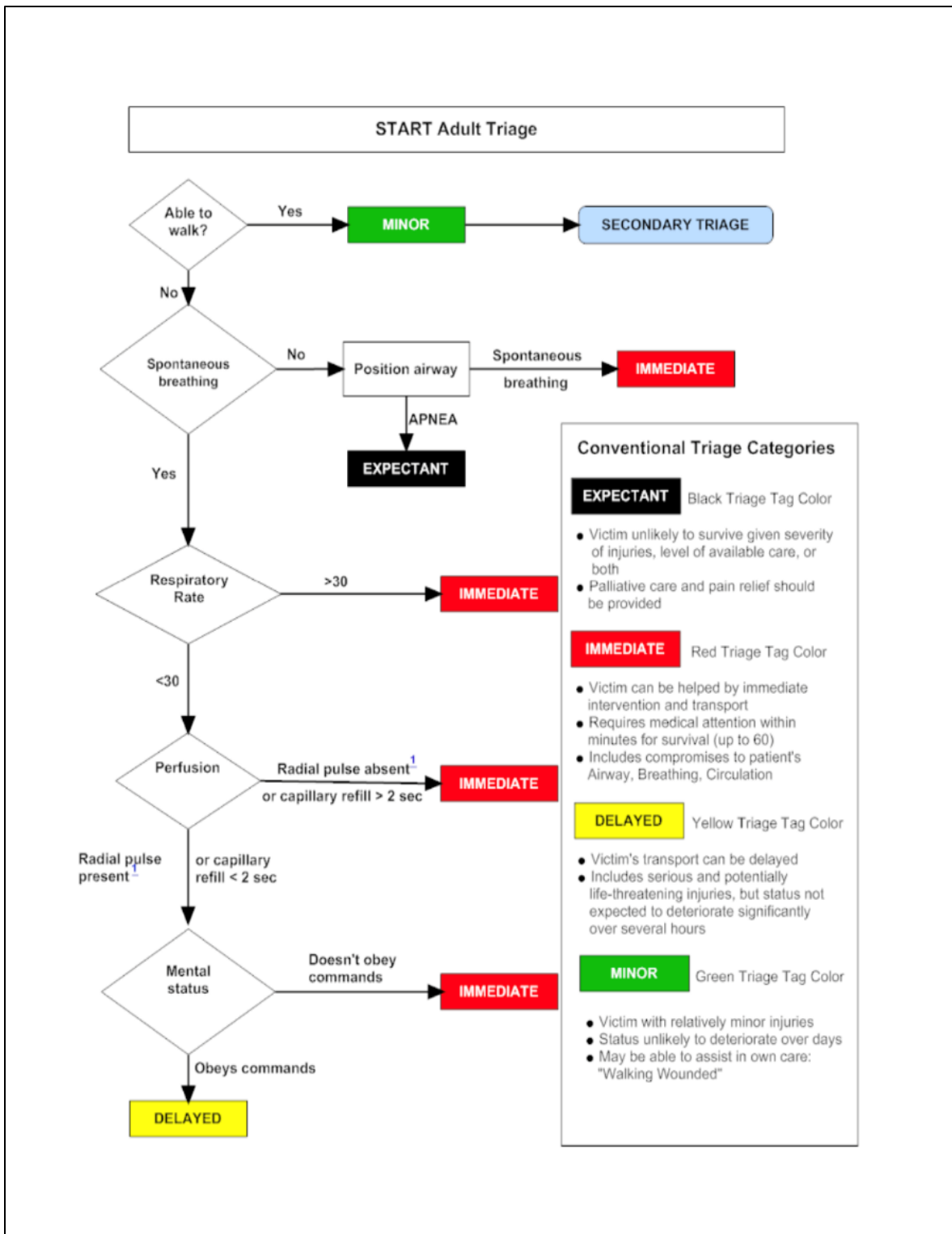


Fig. no. 15.3 – START - Adult Triage

### 5.1.1 Equipment for Radiation dose assessment in RN emergencies

Effective triage requires specific tools, especially during radiation or nuclear incidents. Equipment to assess radiation dose includes:

Equipment	Purpose / Function	Units Measured	Typical Use Scenario	Advantages / Limitations
Geiger-Muller (GM) Counter	Measures ionizing radiation levels	Counts per minute (CPM), $\mu\text{Sv/h}$	Surveying areas for radiation hotspots; initial contamination check	<b>Advantages</b> <ul style="list-style-type: none"> <li>• Simple and portable</li> <li>• Detects beta and gamma radiation</li> </ul> <b>Limitations</b> <ul style="list-style-type: none"> <li>• Less sensitive to alpha radiation, cannot provide cumulative dose</li> </ul>
Alpha Radiation Survey Meter	Detects alpha radiation	Counts per second (CPS), $\text{Bq/cm}^2$	Checking for alpha contamination on surfaces, equipment, and skin	<b>Advantages</b> <ul style="list-style-type: none"> <li>• Sensitive to alpha particles</li> </ul> <b>Limitations</b> <ul style="list-style-type: none"> <li>• Alpha detection requires close proximity, limited penetration</li> </ul>
Personal Use Dosimeter	Measures individual radiation dose exposure	mSv (milli sievert), R (roentgen)	Worn by responders or staff to monitor cumulative exposure over time	<b>Advantages</b> <ul style="list-style-type: none"> <li>• Tracks accumulated dose+ Useful for regulatory compliance</li> </ul> <b>Limitations</b> <ul style="list-style-type: none"> <li>• Does not provide real-time location-based radiation mapping</li> </ul>

Table no.15.1 – Equipment for Radiation dose assessment in RN emergencies

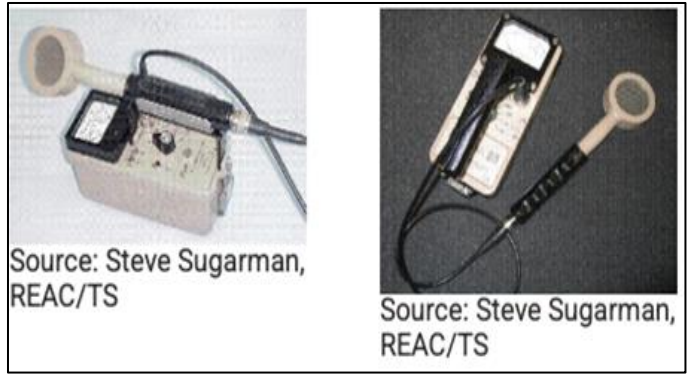


Fig. No. 15.4 -- Geiger Muller Counter



Fig. No. 15.5-- Alpha Radiation Survey Meter



Fig. No. 15.6 -- Personal use dosimeter

## 5.2 Step 2 triage in Radiological & Nuclear Emergencies

Conducted in the cold zone, Step 2 triage involves more thorough evaluation and use of equipment. It is tailored to the nature of the RN agent

In radiological or nuclear emergencies, triage decisions must be made rapidly and accurately to prioritize patients for life-saving care. The four major parameters used to determine triage category are:

- ❖ **Physical Injury Severity of Trauma and/or Burn Severity:** based on the extent of burns (using total body surface area - TBSA) and the depth (partial or full thickness) of trauma or injuries.
- ❖ **Radiation Dose:** estimated exposure from whole or partial body irradiation helps determine the risk of acute radiation syndrome (ARS) and prognosis.
- ❖ **Resource Availability:** consideration of available medical staff, equipment and supplies, and space influences who can receive immediate care versus delayed management.
- ❖ **Co-morbid Diseases:** pre-existing medical conditions may affect treatment success and help guide decisions in resource-limited scenarios.

This multi-factor approach ensures medical resources are directed efficiently, especially during mass casualty radiological events.

### **5.2.1 Triage during radiological and nuclear events as per degree of trauma or burns**

In large-scale radiological or nuclear emergencies, effective triage of trauma patients is essential, particularly when medical resources are limited. Patients are categorized based on the risk to life, urgency of care, and likelihood of survival.

- ❖ **Minimal trauma** patients have minor injuries that pose no significant threat to life or limb over the next 3–4 days, allowing treatment to be safely delayed until referral is possible.
- ❖ **Moderate trauma** patients may deteriorate rapidly without stabilization, but with prompt care, the mortality risk remains below 20%.
- ❖ **Severe trauma** patients require urgent and complex medical interventions, and even with treatment, the risk of death exceeds 20%.
- ❖ **Combined injury** cases involve a radiation dose of  $\geq 2$  Gy along with moderate or severe trauma and/or burns covering  $\geq 20\%$  of the body surface area (BSA), representing highly critical scenarios that pose complex clinical challenges. This classification supports evidence-

based triage decisions and guides the rational allocation of limited healthcare resources during mass casualty incidents.

This classification guides the allocation of limited healthcare resources during mass casualty incidents and supports evidence-based triage decisions.

Trauma Category Definition for Scarce Resources Project	Description
Minimal Trauma	<ul style="list-style-type: none"> <li>• Injuries pose no significant risk to life and limb in next 3-4 days</li> <li>• Limited or no treatment before referral in the next 3-4 days is safe</li> </ul>
Moderate Trauma	<ul style="list-style-type: none"> <li>• Without medical stabilization, possible death within hours</li> <li>• &lt; 20% chance of death with stabilization and treatment</li> </ul>
Severe Trauma	<ul style="list-style-type: none"> <li>• Stabilization requires prompt complex treatment</li> <li>• &gt; 20% chance of death even with prompt treatment</li> </ul>
Combined Injury: Radiation plus significant trauma and/or significant burn	<ul style="list-style-type: none"> <li>• Radiation dose <math>\geq 2</math> Gy to whole or significant partial body</li> <li>+ moderate or severe trauma</li> <li><math>\pm</math> partial of full thickness burn involving <math>\geq 20\%</math> BSA.</li> </ul>

Fig. no. 15.7-- Triage in Radiological and Nuclear Emergencies-as per Degree of trauma/burns  
Source:

### 5.2.2 Triage during radiological and nuclear events as per urgency and survivability

In the context of mass radiation emergencies where medical resources are limited, a specialized triage framework—Scarce Resources Project—is used to categorize patients by urgency and survivability. This model ensures that resources are used efficiently to save the maximum number of lives, while considering injury severity and radiation exposure levels. The system includes five color-coded categories:

❖ <b>Expectant (Black)</b>
❖ Patients receive <b>palliative care only</b> due to extremely poor prognosis.
❖ Focus is on comfort and symptom management as resources allow.
❖ <b>Immediate (Red)</b>
❖ High-priority group for <b>early intervention</b> based on injury severity (trauma, burn, radiation, or combined).
❖ These patients may not be the sickest but are most likely to benefit from immediate care.
❖ <b>Delayed (Yellow)</b>
❖ Patients requiring treatment but <b>can tolerate delayed care</b> .
❖ Resources are directed to them after red category patients.
❖ <b>Minimal B (Green)</b>
❖ Minimal or no physical injury with <b>radiation dose between 0.5–2 Gy</b> (assessed by biodosimetry).
❖ Further monitoring and dose assessment may be needed.
❖ <b>Minimal A (Light Green)</b>
❖ Low priority for care, with <b>radiation dose &lt;0.5 Gy</b> and no visible injury.
❖ May receive little to no immediate medical attention.

Box 15.1- Triage during radiological and nuclear events as per urgency and survivability

### 5.2.3 Triage during radiological and nuclear events as per availability of medical resources

The graph as shown in figure 15.8, illustrates the relative availability of medical resources over time (in days) after a nuclear detonation, across different types of medical care facilities. The data highlight how medical capacity degrades and recovers post-detonation, influencing the operative standard of care. Key highlights are as under:

- ❖ **Day 0-1:** All facilities experience an abrupt drop in available resources, especially those closer to the detonation site.
  - **RTR1** (near impact): Drops to *poor* resource levels almost immediately.
  - **Medical Centers (MCs) within 2 miles:** Rapid degradation.
  - **MCs 20 miles and 100 miles away:** Experience a less severe, delayed resource drop.
  
- ❖ **Days 2-4:** Gradual recovery begins in more distant centers.
  - **Distant referral centers and MCs 100 miles away** begin to stabilize towards "good" capacity.
  - **RTR1** remains in crisis for an extended period.
  
- ❖ The graph maps **shifting standards of care:**
  - **Conventional care:** When resources are normal.
  - **Contingency care:** When resources are strained.
  - **Crisis care:** When resources are extremely limited, requiring triage and care rationing.

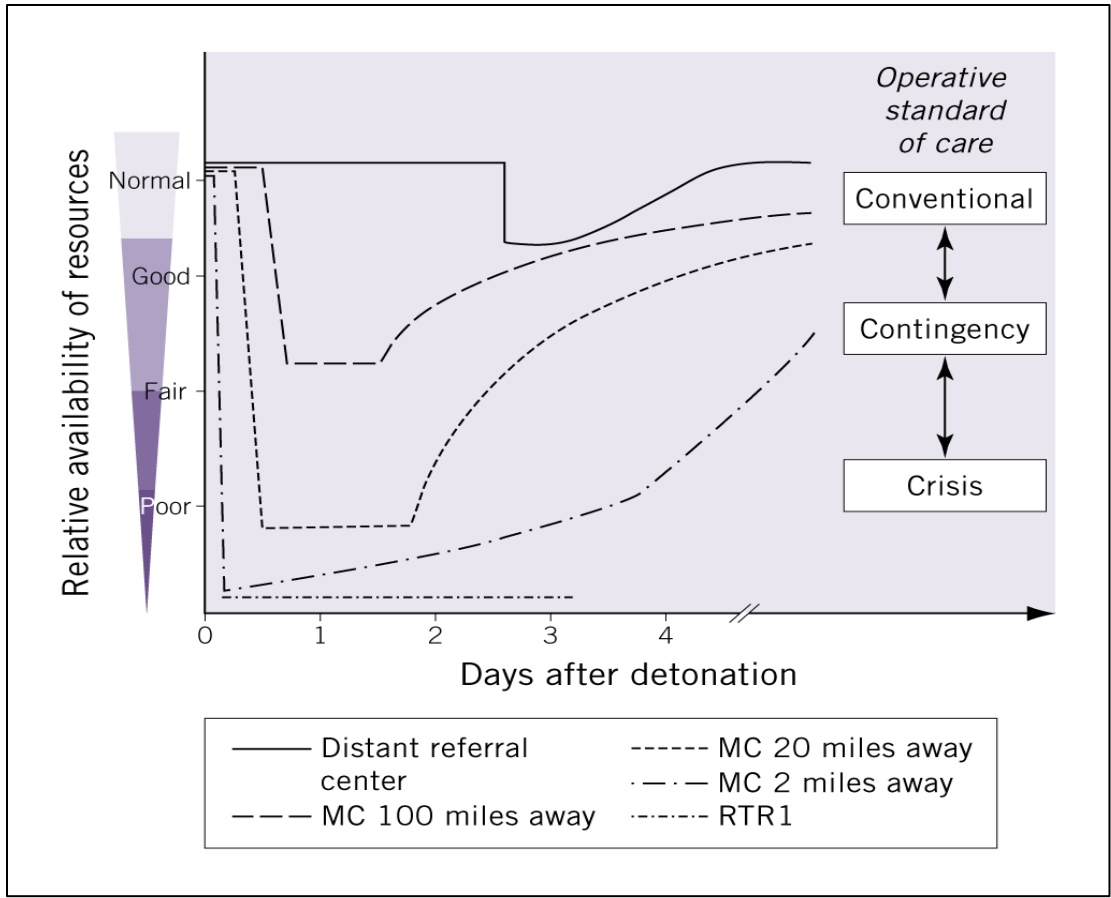


Fig. no. 15.8– Triage during radiation/nuclear events as per availability of medical resources

**5.2.4 Triage in Radiation and Nuclear Emergencies as per trauma and radiation exposure**

Figure 15.9 presents a systematic triage framework for managing casualties in the event of a nuclear or radiological disaster, where both radiation exposure and injury severity must be considered simultaneously.

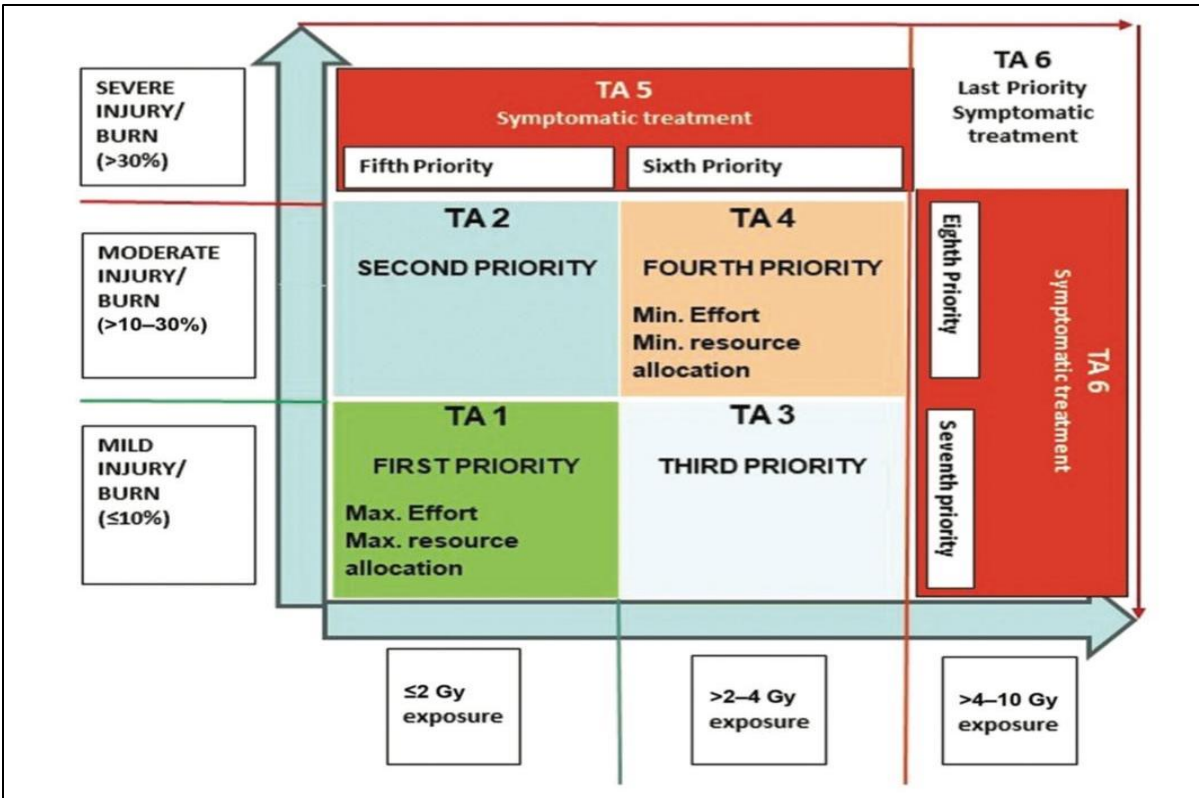


Fig. no. 15.9-- Matrix-Based Triage in Radiation and Nuclear Emergencies as per trauma and radiation exposure

❖ **Purpose of the Matrix-Based Triage:** In a nuclear disaster, victims may have burns, trauma, or combined injuries. Many may also be exposed to ionizing radiation and resources (staff, beds, medications) are limited. Hence, triage must maximize survival by prioritizing patients based on both injury and radiation exposure.

This is a 2D grid matrix, with vertical axis representing the severity of physical injury or burn, categorized as:

- Mild [≤10 % Body Surface Area (BSA) or minor trauma]
- Moderate (10–30% BSA or moderate trauma)
- Severe (>30% BSA or severe trauma)

The horizontal axis represents the estimated radiation dose, categorized as:

- ≤2 Gy (low)
- 2–4 Gy (moderate)

- 4–10 Gy (high)
- 10 Gy (very high, often fatal)

Radiation Dose	Injury Severity	Triage Category (TA)	Priority	Treatment Guidance
≤2 Gy	Mild (≤10%)	TA 1	First Priority	Max effort and resource allocation
≤2 Gy	Moderate (10–30%)	TA 2	Second Priority	Intensive care needed
>2–4 Gy	Mild (≤10%)	TA 3	Third Priority	Moderate support
>2–4 Gy	Moderate (10–30%)	TA 4	Fourth Priority	Minimal effort/resource allocation
>4–10 Gy	Any injury severity	TA 5	Fifth–Sixth Priority	Symptomatic treatment; survival uncertain
Any Gy	Severe burn/injury >30%	TA 6	Last Priority	Palliative care / symptomatic treatment only

Table no.15.2 – Summary of 2D grid mix matrix triage

### Take Home Message:

- ❖ Triage in RN emergencies is done in two steps
  - Step 1 Triage-Mass Casualty triage as per severity of trauma or burns
  - Step 2 Triage-Combined radiation plus severity of injury or burns triage
- ❖ Radiation detection and monitoring equipment (survey meters, dose rate meters, portable spectrometers, personal dosimeters) are used to assess exposure and contamination in real-time.

### References (Adapted from)

- Smith JM, Ansari A, Harper FT. Hospital management of mass radiological casualties: reassessing exposures from contaminated victims of an exploded radiological dispersal device. Health Phys. 2005 Nov;89(5):513-20. [PubMed Citation]

- Planning Guidance for Response to a Nuclear Detonation, 3<sup>rd</sup> ed. (PDF - 2.62 MB) (FEMA, 2022)
- Bazyar J, Farrokhi M, Salari A, Khankeh HR. The Principles of Triage in Emergencies and Disasters: A Systematic Review. *Prehosp Disaster Med.* 2020 Jun;35(3):305-313. [PubMed Citation]
- Guidelines for Field Triage of Injured Patients, Recommendations of the National Expert Panel on Field Triage (CDC/MMWR Recommendations and Reports 58(RR01);1-35, January 23, 2009)
- Hick JL, Bader JL, Coleman CN, Ansari AJ, Chang A, Salame-Alfie A, Hanfling D, Koerner JF. Proposed "Exposure and Symptom Triage" (EAST) Tool to Assess Radiation Exposure After a Nuclear Detonation. *Disaster Med Public Health Prep.* 2018 Jun;12(3):386-395.
- Bowen TE, Bellamy RF, eds. *Emergency War Surgery NATO Handbook*. 2nd rev US ed. Washington, DC: Department of Defence, Government Printing Office; 1988.
- Urbanetti JS. Clinical Assistant Professor of Medicine, Yale University School of Medicine, New Haven, Conn. Personal communication, 1989.
- Keeler JR. Interactions between nerve agent pretreatment and drugs commonly used in combat anesthesia. *Milit Med.* 1990; 155:527–533.
- Zhao, Feida & Zhao, Chao & Bai, Song & Yao, Lulu & Zhang, Yongzhong. (2023). Triage Algorithms for Mass-Casualty Bioterrorism: A Systematic Review. *International Journal of Environmental Research and Public Health.* 20. 5070. 10.3390/ijerph20065070.
- WHO. (2006). *Health effects of the Chernobyl accident and special health care programmes*. Geneva: WHO Press.
- Bromet, E. J. (2014). Emotional consequences of nuclear power plant disasters. *Health Physics,* 106(2), 206–210.
- ICRP. (2007). *The 2007 Recommendations of the International Commission on Radiological Protection*. ICRP Publication 103.
- AIIMS NDMA Training Resources on RN Preparedness.

- United Nations Office for the Coordination of Humanitarian Affairs (OCHA). (2015). Emergency response coordination.
- IAEA Manual for First Responders to a Radiological Emergency (EPR-First Responders) <https://www.iaea.org/publications/7606/manual-for-first-responders-to-a-radiological-emergency>
- IAEA- Practical Radiation Monitoring and Dose Evaluation
- WHO – Manual for the Public Health Management of Radiological and nuclear events (2020)
- BARC – Emergency Preparedness for Nuclear and Radiological Emergencies: Guidelines for First Responders
- AERB – Safety Guide on Emergency Preparedness in Nuclear and Radiological Facilities (AERB/NRF-EP/SG-1)
- IAEA/WHO – EPR-Medical (2005) and REMM (Radiation Emergency Medical Management) resources
- WHO (2017). Clinical Management of Radiation Emergencies. <https://www.who.int/publications/i/item/9789241550185>
- Image Sources:
  - Fig.no. 15.1 (adapted from: Ottawa Handbook of Emergency Medicine <https://emottawablog.com/wp-content/uploads/2023/01/CBRNE-595x336.png>)
  - Fig.no. 15.2 (IAEA 2005)
  - Fig.no. 15.3  
(<https://www.sciencedirect.com/science/article/abs/pii/S2405799119300568>)
  - Fig.no. 15.4,15.5,15.6 (Radiation Emergency Assistance Center/Training Site and <https://www.mirion.com/>)

- Fig.no. 15.7 (WHO (2017). Framework for Triage of Radiation Combined Injury in Scarce Resource Situations (<https://www.who.int/publications/i/item/9789241550185>))
- Fig.no. 15.8 (DiCarlo AL, Maher C, Hick JL, et al. Radiation Injury After a Nuclear Detonation: Medical Consequences and the Need for Scarce Resources Allocation. *Disaster Medicine and Public Health Preparedness*. 2011;5(S1): S32-S44. doi:10.1001/dmp.2011.17)
- Fig.no. 15.9 (Kumar P, Gupta A. A New Method of Matrix-Based Triage for Nuclear Disasters. *Indian J Plast Surg*. 2023 Oct 16;56(6):548-551. doi: 10.1055/s-0043-1775869. PMID: 38105881; PMCID: PMC10721366.)

### **Suggested Reading**

- IAEA (2006) Manual for First Responders to a Radiological Emergency (EPR-First Responders) <https://www.iaea.org/publications/7606/manual-for-first-responders-to-a-radiological-emergency>

## Chapter 16

### Topic: Radiation Dosimetry

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand types of Dosimetry
- Understand the usage of different types of Dosimetry in Accident scenarios
- Understand the importance and details on Bio-dosimetry and Clinical Dosimetry

#### 1. Introduction

Dosimetry is the science of measuring radiation dosage. The absorbed dose of radiation is measured in a unit called “gray” (Gy). Radiation dosage measurements and ensuring they are as accurate as possible are important if the benefits of the application of nuclear technology in health care are to be harnessed. Radioactive processes and radiation are utilized in many health related technologies, and the requirement for Quality Assurance (QA) and accuracy in dosimetry depends upon the specific needs of the particular applications.

The fundamental quantity in radiation dosimetry is the absorbed dose, defined as the energy imparted by ionizing radiation per unit mass of the absorbing medium and expressed in grays (Gy), where  $1 \text{ Gy} = 1 \text{ joule/kg}$ . Additional dosimetric quantities such as equivalent dose and effective dose are used for risk estimation, incorporating radiation type and tissue-specific weighting factors, respectively.

## 2. Definition:

Radiation dosimetry is the science of measuring or calculating absorbed dose (or dose rate) in matter exposed to ionizing radiation. It is a broad discipline covering measurements and calculations of internal and external irradiation.

Dosimetry is crucial for assessing radiation exposure in various settings, including healthcare, research, and occupational settings.

## 3. Applications of Radiation Dosimetry in Health

Radiation dosimetry is essential in health for ensuring safe, effective, and optimized use of ionizing radiation in both diagnostic and therapeutic settings.

### ❖ Diagnostic Imaging

In CT, fluoroscopy, and radiography, dosimetry quantifies patient exposure using metrics like volume computed tomography dose index (CTDI<sub>vol</sub>) and dose length product (DLP), supporting optimization to minimize stochastic risks such as radiation-induced cancers. Organ-level dosimetry using computational phantoms enables age- and size-specific dose estimates.

### ❖ Nuclear Medicine

Dosimetry calculates absorbed dose to organs from radiopharmaceuticals, supporting both diagnostics (e.g., <sup>99m</sup>Tc, <sup>18</sup>F) and therapies (e.g., <sup>177</sup>Lu-DOTATATE - delivers ionizing radiation that targets tumor cells expressing somatostatin receptors, causing radiation-induced single- and double-stranded DNA breaks that lead to apoptosis). Tools like Organ Level Internal Dose Assessment/Exponential Modeling (OLINDA/EXM - industry-standard dosimetry software for uniform dose calculations for diagnostic and therapeutic radiopharmaceuticals) allow personalized internal dosimetry, crucial for balancing efficacy and toxicity.

### ❖ Radiation Therapy

In radiotherapy (intensity-modulated radiation therapy- IMRT, Stereotactic body radiation therapy-SBRT, proton), dosimetry ensures precise tumor targeting while sparing healthy tissue.

Ionization chambers, TLDs, and Monte Carlo models support treatment planning, verification, and QA. In brachytherapy, TG-43 protocols guide source-specific dose calculations.

#### ❖ **Occupational & Patient Protection**

Healthcare workers use personal dosimeters (TLDs, Optically stimulated luminescence dosimeters-OSLDs) to monitor  $H_p(10)$  and  $H_p(0.07)$ [which represent the personal dose equivalent at a depth of 10 mm and 0.07 mm, respectively]. Dosimetry also guides shielding design, ensures regulatory compliance, and supports dose auditing in high-risk departments like cath labs and nuclear medicine.

#### **4. Types of Radiation Dosimetry:**

Accident Dosimetry can be broadly divided into:

- Clinical Dosimetry
- Biological Dosimetry
- Physical Dosimetry

##### **4.1 Clinical Dosimetry**

Clinical dosimetry refers to the clinical assessment of the probable radiation dose received by a patient, either during a radiation accident or as part of radiotherapy treatment. In the context of a radiation accident, clinical dosimetry based on the evaluation of clinical signs and symptoms serves as the most immediate and practical approach for dose estimation. It is often the only available modality for clinicians to initiate medical management prior to the availability of results from physical or biological dosimetry. Furthermore, physical dosimetry methods such as Thermoluminescent Dosimeters (TLDs) or Direct Reading Dosimeters (DRDs) may not be accessible, particularly in scenarios involving public exposure, thus emphasizing the critical role of clinical dosimetry in early triage and intervention.

The aims of clinical dosimetry involve the clinical examination of the affected individual to assess the radiation dose received for effective triage and immediate treatment planning. It includes

dose verification, assessment of individual prognosis, and the establishment of defined protocols for long-term monitoring and follow-up of such patients.

The determinants of clinical dosimetry comprise clinical history, clinical observations, symptomatology, physical signs, and relevant laboratory investigations. Clinical history involves a detailed account of exposure to ionizing radiation, including the time, location, nature, magnitude of exposure or contamination or intake, and the number of individuals likely to be affected. Clinical observations are crucial in cases of acute whole-body exposure exceeding 1 Gray, where prodromal symptoms and signs serve as critical indicators.

Symptoms may include nausea, fatigue, malaise, anorexia, drowsiness, abdominal pain or cramps, and headache. Notable signs include vomiting—where the time to emesis is vital for dose estimation—diarrhea, which is an ominous sign indicating a high exposure of greater than 6 to 8 Gy, and cutaneous manifestations such as oedema, erythema, hypotension, hyperpyrexia, disorientation, prostration, loss of coordination, and potentially seizures, suggesting a very high CNS or neurovascular dose range.

In cases of local exposure exceeding 3 Gray, clinical signs may include local irritation, erythema, epilation, scaling (dry desquamation), bullae or blister formation, ulceration, necrosis, and gangrene. Laboratory evaluation through complete blood count (CBC) with differential and absolute lymphocyte count is also a key determinant in clinical dosimetry.

Vomiting in ____ of incident	Estimated dose
Less than 10 minutes	> 8 Gy
10 - 30 minutes	6 - 8 Gy
Less than 1 hour	4 - 6 Gy
1 - 2 hours	2 - 4 Gy
After 2 hours	< 2 Gy

Table no. 16.1- Clinical Dosimetry Triage

## 4.2 Biological Dosimetry

Biological Dosimetry is based on radiation-induced DNA damage and mis-repair, which can be detected by various cytogenetic assays. Blood circulates throughout the body: averaging the dose from all parts of the body. Blood samples should be taken days to a few weeks after exposure. If blood sampling is delayed to several weeks or more, this delay has to be considered by correcting for the half-life of the biological marker. There is a variety of emerging bio-dosimetry assays rooted in “**omic**” approaches. It is highly unlikely that there will ever be a single, ideal bio-dosimetry method. The strongest application will likely come from combined or sequential approaches tailored to specific scenarios.

**Omic approaches** are a group of biological methods that analyze the entire set of a biological molecule, such as genes, RNA, proteins, or metabolites. These high-throughput techniques provide a comprehensive view of an organism's molecular components, with common examples including genomics (genes), transcriptomics (RNA), proteomics (proteins), and metabolomics (metabolites). By integrating data from multiple omics layers, a "multi-omics" approach can provide deeper insights into complex biological systems and disease mechanisms.

Box 16.1

## 4.3 Physical Dosimetry

Physical radiation dosimetry involves quantifying radiation exposure using materials that are either biologically derived from individuals—such as teeth or nails—or are non-biological personal items, like electronics or clothing. These materials can serve as passive dosimeters, especially in retrospective dosimetry following radiological incidents. The primary purpose of quantitative dose estimation is to predict potential biological effects or material modifications induced by ionizing radiation and to ensure the implementation of effective radiation protection and safety protocols. Physical dosimetry employs several techniques, including ionization chambers, photo-dosimetry, thermoluminescence (TL), optically stimulated luminescence (OSL), calorimetry, and electron paramagnetic resonance (EPR) spectroscopy.

## **5. Personal Dosimeters**

Among personal dosimeters, film badge dosimeters were traditionally used in India, relying on the degree of blackening of photographic film to estimate dose. Although advantageous for long-term storage of dose records, these badges were single-use and required chemical development before readings could be taken. Thermoluminescent dosimeters (TLDs) and optically stimulated luminescence dosimeters (OSLs) offer reusable alternatives, working on the principle of trapping electrons or holes at defect sites during radiation exposure and subsequently releasing them upon stimulation. However, these dosimeters typically allow accurate readings only up to two times before signal degradation occurs. Another type, CR-39 (Columbia Resin 39), a solid-state nuclear track detector (SSNTD), is primarily used for neutron dosimetry. Neutron interactions produce visible damage tracks in the polymer matrix, which can be chemically etched and analyzed. In India, dysprosium doped calcium sulphate-  $\text{CaSO}_4:\text{Dy}$ -based TLD badges are routinely used for monitoring x-ray, gamma, and beta radiation exposures, while neutron exposures are assessed using CR-39 SSNTDs, reflecting the diversity and specificity of physical dosimetric tools in radiation safety management.

## **6. General Precautions During Use of Dosimeters and Choice of Dosimetry Techniques**

### **6.1 General Precautions During Use of Dosimeters**

Proper handling and usage of dosimeters, particularly Thermoluminescent Dosimeters (TLDs), are critical for accurate dose assessment and ensuring radiation safety. A control card must always accompany the batch of dosimeters as it records background or transient doses and should be stored in a radiation-free area. Both used and unused TLD badges, including the control, should be kept away from active radiation sources, such as X-ray machines or radioactive materials, to prevent unintentional exposure. During routine use, the dosimeter should be worn at chest level to monitor the whole-body dose and must be placed under the lead apron, if one is worn. In cases where extremities are likely to be exposed—such as handling low-energy photons (<15 keV) or beta particles—a wrist TLD badge is recommended. For potential radiation exposure to the eyes or head, head badges can be used to monitor localized doses.

The choice of biological dosimetry techniques depends on the type and extent of radiation exposure. The dicentric chromosome assay (DCA) is considered the gold standard and is routinely used for assessing doses in the range of 50 mGy to 6 Gy due to its high specificity and reliability. For very high-dose exposures (100 mGy to 25 Gy), the premature chromosome condensation (PCC) assay is more appropriate, especially when mitotic cells are unavailable. The translocation assay using fluorescence in situ hybridization (FISH) is particularly valuable in retrospective dosimetry, offering long-term dose estimation due to the stable nature of translocations in peripheral lymphocytes. Additionally, the micronucleus assay serves as a useful high-throughput tool for large-scale prescreening during radiological emergencies or population-level surveillance. Each method offers specific advantages and is selected based on the exposure context, time since irradiation, and logistical feasibility.

## 6.2 Choice of Dosimetry Techniques

- ❖ **Dicentric Chromosome Assay (DCA)** is considered the “gold standard” for bio-dosimetry. Radiation exposure causes DNA strand breaks. During the repair of these DNA strand breaks, mis-repair of two chromosomes and abnormal chromosome replication can lead to the formation of dicentric chromosomes. DCA has the disadvantage that it requires 2 days of culture plus scoring time before results become available. Above 5 Gy, the dicentric chromosomes will deviate from the calibration curve, resulting in an underestimation of the dose.
- ❖ **Cytogenetic dosimetry** assesses ionizing radiation exposure by analyzing radiation-induced chromosomal aberrations in peripheral blood lymphocytes. Within the dose range of 50 mGy to 6 Gy, this is achieved by identifying dicentric chromosomes formed as a result of the mis-repair of DNA double-strand breaks. The Dicentric Chromosome Assay (DCA) is the **gold standard in cytogenetic dosimetry**, detecting unstable aberrations such as dicentrics with high specificity and reliability, particularly for acute exposures up to approximately 5 Gy. However, its accuracy diminishes at higher doses due to cell cycle arrest and the presence of complex chromosomal aberrations. The technique requires approximately 48 hours for lymphocyte

culture, followed by manual or semi-automated scoring, which limits its applicability in scenarios requiring rapid dose assessment, such as mass casualty events.

➤ **Authorized Agencies for Cytogenetic Dosimetry**

- Bhabha Atomic Research Centre (BARC), Mumbai, Maharashtra
  - Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, Tamil Nadu
  - Sri Ramchandra Medical College (SRMC), Chennai, TamilNadu
  - Institute of Nuclear Medicine & Allied Sciences (INMAS- DRDO), New Delhi
- ❖ **Premature Chromosome Condensation (PCC):** To overcome the shortcomings of DCA for high exposures, PCC was introduced. This method forces chromosomes to condense in any stage of the cell cycle, making it possible to distinguish individual chromosomes and therefore chromosomal aberrations such as dicentrics, rings, or translocations. The method can be used from very low doses up to very high within hours of blood sampling while maintaining a high accuracy over a large dose range (0 Gy to 20 Gy). The PCC assay, like the DCA, is well suited for acute exposure, but limited after exposure from internal radionuclides, chronic exposure, or exposures a long time in the past.
- ❖ **Cytokinesis-block micronucleus cytome (CBMN):** assay Micronuclei (MNs) result from the formation of small fragments of chromosome material that lack the ability to interact with the mitotic spindle during anaphase. They form small separate nuclei in the cytoplasm. Ionizing radiation can induce MNs during cell division in a dose-dependent manner through the process of creating unrepaired DNA double-strand breaks (DSBs). MNs are counted only in binucleated cells (BNCs), hence the name cytokinesis-block micronucleus (CBMN) assay. MNs are not uniquely induced by ionizing radiation exposure.
- ❖ **Translocation analysis by FISH:** Dicentric Chromosome Assay (DCA) and Cytokinesis-Block Micronucleus (CBMN) assay detect unstable chromosomal aberrations that diminish over time following radiation exposure. In contrast, translocations, although not all are stable, tend to persist longer in peripheral blood lymphocytes and can therefore be utilized for dose assessment long after the initial exposure. The advent of fluorescent whole-chromosome painting techniques has enabled the reliable detection of translocations, making translocation analysis by Fluorescence in Situ Hybridization (FISH) a viable approach for retrospective bio-

dosimetry. However, the FISH technique is associated with higher costs and involves a longer and more complex staining protocol, which limits its practical use in emergency bio-dosimetry scenarios.

- ❖ **The  $\gamma$ -H2AX assay** is based on the detection of DNA double-strand breaks (DSBs), which are considered the most biologically significant lesions resulting from ionizing radiation. One of the earliest cellular responses to DSBs is the phosphorylation of serine 139 of the H2AX histone, resulting in the formation of  $\gamma$ -H2AX foci at the break sites, with a one-to-one correspondence. The use of fluorescent markers specific to  $\gamma$ -H2AX enables the visualization of these foci, providing a means to quantify DNA damage. In lymphocytes, the dose response has been demonstrated to be linear up to 10 Gy, and under well-controlled conditions, the assay can detect doses as low as a few milligray. Samples can be processed and analyzed immediately, although background levels of  $\gamma$ -H2AX may vary between individuals and are influenced by factors such as age and smoking.
- ❖ **Emerging assays:** Radiation exposure initiates complex cascades of signaling events, leading to broad alterations in the cellular transcriptional program, as well as changes in the levels, localization, and activation status of both signal transduction and effector proteins. Additionally, radiation induces modifications in cellular, tissue, and organismal metabolism. In response to these multifaceted effects, bio-dosimetry assays are being developed to quantify radiation-induced changes at the RNA, protein, and small molecule metabolite levels. These emerging methodologies utilize “-omics” technologies, including transcriptomics, proteomics, and metabolomics. RNA expression-based, protein-based, and metabolomics-based assays represent promising approaches, though they are currently under development and have not yet been standardized.

Method	Cells Studied	Optimal Test Period After Exposure	Exposure Pattern Reliably Detected	Applicable Range
Dicentrics	Lymphocytes	Days to weeks	Acute – whole/partial body	0.1–5 Gy
Translocations	Lymphocytes	Retrospective	Acute/Chronic – whole body	0.3–5 Gy
PCC	Lymphocytes	Hours–Days	Acute – whole/partial body	0.1–20 Gy
Micronuclei	Lymphocytes	Days–Weeks	Acute – whole body	0.3–5 Gy

Table no. 16.2 – Biological Dosimetry

## 7. Guide for management of radiation injuries on the basis of early symptoms

The early clinical symptoms are the basis for sorting persons exposed to radiation and deciding upon proper medical care at an individual level. The most important prodromal early clinical signs are nausea, vomiting, diarrhea, skin and mucosa erythema.

The decision on hospitalization, in cases of whole body exposure, depends on the presence of early clinical signs as set forth in this slide.

Patients in the emergency room manifesting nausea and vomiting should be treated symptomatically and should be monitored with daily blood counts. Victims who have received doses from external radiation of less than 1 Gy might be followed up as outpatients if the laboratory test (absolute lymphocyte count) results and dose estimate seem appropriate. (Refer Table 16.3,16.4 and 16.5)

Symptom	Dose	Action required
No vomiting	< 1 Gy	Outpatient with 5-week surveillance
Vomiting in 2-3 h	1-2 Gy	Surveillance in a general hospital (or outpatient for 3 weeks) followed by hospitalization
Vomiting in 1-2 h	2-4 Gy	Hospitalization in a hematological department
Vomiting in < 1 h Diarrhea Erythema	> 4 Gy	Hospitalization in a well-equipped hematological or surgical department with transfer to a specialized center for GFs / BMT

Table no. 16.3- Guide for management of radiation injuries on the basis of early symptoms

**Skin Sign:**

Nature of radiation injury	Absolute lymphocyte count	Dose range (Gray)
Mild	1500 -2000	1 –2 Gy
Moderate	1000 -1500	2 –4 Gy
Severe	500 -1000	4 –6 Gy
Very severe	100 -500	6 –8 Gy
Lethal	< 100	> 8 Gy

Table no. 16.4- Skin Sign

**Skin changes after radiation exposure provides approximate dose:**

Skin Sign	Dose	Time of appearance
Transient Erythema	3 Gy	in a few hours
Temporary Epilation	3 Gy	in 2-3 weeks
Fixed Erythema	6 Gy	in 2-3 weeks
Permanent Epilation	6 Gy	
Dry Desquamation	10 Gy	in 4-6 weeks
Wet Desquamation	20 Gy	
Ulcer, Necrosis	30 Gy	in 6 months

Table no. 16.5- Skin changes after radiation exposure provides approximate dose

**8. Blood sampling**

**8.1 Timing**

- A veni-puncture blood sample, preferably 10 mL, could be taken within a few hours of a whole body radiation exposure. However, in the case of a partial-body or non-uniform exposure the lymphocytes in the circulating and extravascular pools will not have reached equilibrium until about 24 hours. This could result in an unrepresentative proportion of irradiated cells in the specimen and therefore delaying sampling until at least the next day is advisable.

**8.2 Container**

- Blood should be collected in disposable glass or plastic specimen tubes containing the correct amounts of lithium heparin, which is available from several manufacturers.

### **8.3 Anticoagulant**

- Preservative free lithium heparin is the most commonly used anticoagulant for lymphocyte cultures, although it is possible to use sodium or ammonium heparin.
- Other commonly available anticoagulants, e.g. ethylenediaminetetraacetic acid (EDTA), often result in poor cell growth and should not be used.

### **8.4 Transport**

- Blood specimens should be maintained ideally between 18 and 24°C during transportation.
- During air transport the blood should not be X rayed in security checks.
- If this is likely, a piece of X ray film or a standard Thermoluminescent Dosimeter (TLD) or Optically Stimulated Luminescence (OSL) monitoring badge could be included in the package.
- A 'DO NOT X-RAY' label should be placed on the package.

### **8.5 Absolute Lymphocyte Count (ALC):**

Lymphocytes are highly sensitive to ionizing radiation due to their high nuclear-to-cytoplasmic ratio making them one of the earliest hematopoietic cells to show measurable effects after exposure (this structural feature makes them highly sensitive to ionizing radiation, because radiation primarily damages DNA in the nucleus). Following a significant radiation event, the absolute lymphocyte count (ALC) drops rapidly, often serving as the earliest indicator of the severity of exposure.

Monitoring ALC over time provides critical prognostic information in cases of suspected radiation injury. Andrew's Nomogram is a widely used clinical tool that illustrates lymphocyte depletion kinetics, allowing clinicians to estimate the dose of radiation received and predict the potential severity of Acute Radiation Syndrome. This approach enables timely triage and informed decision-making for the management of exposed individuals.

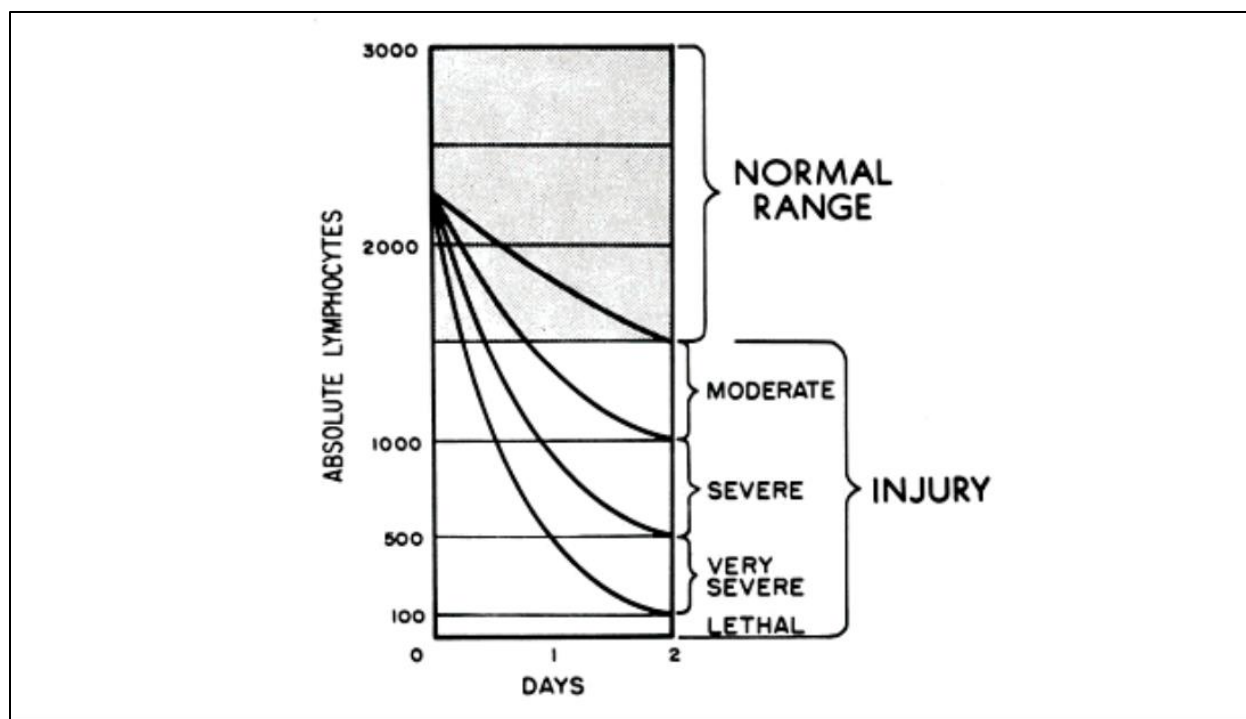


Fig.no.16.1- Andrew's Nomogram

## 9. Conclusion

In the event of radiation accidents, it is crucial to estimate the absorbed radiation doses in affected individuals to enable appropriate medical intervention. However, in most such incidents, especially those involving the public domain, physical dosimetry is often not feasible. Even when physical dosimetry is possible, obtaining results may be delayed due to logistical challenges, and it is essential to corroborate these estimates through additional methodologies. Biological dosimetry techniques, such as cytogenetic analysis of chromosomal aberrations in peripheral blood lymphocytes—including dicentric, translocations, premature chromosome condensation (PCC), and micronuclei assays—are valuable tools for dose estimation, although they also require significant time for result generation.

### Take Home Message:

- ❖ Radiation dosimetry can be broadly classified into Clinical, Biological and Physical Dosimetry
- ❖ Clinical Dosimetry helps to ascertain approximate dose in case of mass casualty based on clinical symptoms like duration of onset for Nausea and Vomiting
- ❖ In Biological Dosimetry, dicentric assay is most accurate for the dose estimation
- ❖ Physical dosimetry measures absorbed radiation dose using devices (TLDs, OSLDs, film badges, survey meters) to provide immediate assessment, monitor contaminated areas, aid dose reconstruction, and guide safe entry and decontamination.
- ❖ Pattern of Lymphocyte depletion also helps in predicting doses received
- ❖ Surgical intervention is justified whenever irreversible alterations appear

### References: (Adapted from)

- Journal of the International Commission on Radiation Units and Measurements (ICRU) (2011) Report 85: Fundamental Quantities and Units for Ionizing Radiation.
- ICRP Publication 103 (2007) Recommendations of the International Commission on Radiological Protection. Ann ICRP. 2007;37(2-4):1-332.
- Stabin MG. Radiation Protection Dosimetry: A Practical Introduction to Dose Calculations. 1st ed. CRC Press; 2007.
- Ainsbury EA, et al. Review of retrospective dosimetry techniques for external ionising radiation exposures. RadiatProt Dosimetry. 2011;147(4):573-592.
- Ma CM, et al. A review of Monte Carlo codes for radiotherapy dosimetry. Phys Med Biol. 1999;44(10):R157-R183.
- Hall EJ, Giaccia AJ. Radiobiology for the Radiologist. 7th ed. Lippincott Williams & Wilkins; 2012.

- Review of Radiation Oncology Physics: A Handbook for Teachers and Students-  
[https://www.irsn.fr/sites/default/files/documents/professionnels\\_sante/documentation/syllabus\\_chapitre\\_3.pdf](https://www.irsn.fr/sites/default/files/documents/professionnels_sante/documentation/syllabus_chapitre_3.pdf)
- Andrews GA, Auxier JA, Lushbaugh CC. The Importance of Dosimetry to the Medical Management of Persons Exposed to High Levels of Radiation. In Personal Dosimetry for Radiation Accidents. Vienna: International Atomic Energy Agency; 1965.
- <https://www.iaea.org/resources/hhc/medical-physics/radiotherapy/dosimetry>
- IAEA Technical Report Series No. 405 (2011). Cytogenetic Dosimetry: Applications in Preparedness for and Response to Radiation Emergencies.
- IAEA: EPR Bio-dosimetry, 2011 ([https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-Biodosimetry%202011\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-Biodosimetry%202011_web.pdf))
- Fenech, M. (2000). The in vitro micronucleus technique. *Mutat Res*, 455(1–2), 81–95.
- Lloyd, D. C., Purrott, R. J., & Dolphin, G. W. (2000). Chromosomal aberration dosimetry following whole-body exposure to ionising radiation. *RadiatProtDosim*, 88(2), 133–139.
- Rothkamm, K., & Löbrich, M. (2003). Evidence for a lack of DNA double-strand break repair in human cells exposed to very low x-ray doses. *Proc Natl AcadSci USA*, 100(9), 5057–5062.
- Rogan, P. K., et al. (2016). High-throughput radiation biodosimetry using gamma-H2AX immunostaining and imaging flow cytometry. *Radiat Res*, 185(2), 210–218.
- Image Sources: Fig.no. 16.1 (adapted from Goans, Ronald E., Holloway, Elizabeth C., Berger, Mary Ellen, and Ricks, Robert C. "Early Dose Assessment Following Severe Radiation Accidents", *Health Physics* 72(4): 1997.)

### **Suggested Reading**

- IAEA: EPR Bio-dosimetry, 2011 ([https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-Biodosimetry%202011\\_web.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/EPR-Biodosimetry%202011_web.pdf))
- Radiation Therapy Dosimetry - A Practical Handbook (2021) Arash Darafsheh (<https://www.scribd.com/document/730365408/Radiation-Therapy-Dosimetry-a-Practical-Handbook>)
- Dose Estimator for Exposure: 3 Bio-dosimetry Tools ([https://remm.hhs.gov/ars\\_wbd.htm](https://remm.hhs.gov/ars_wbd.htm))

## Chapter 18

### Acute Radiation Syndrome (ARS) and Cutaneous Radiation Injuries (CRI)

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Identify and evaluate early symptoms of ARS.
- Conduct physical and diagnostic assessments.
- Apply evidence-based management of ARS sub-syndromes.
- Implement infection prevention and treatment protocols.
- Understand the indications and limitations of bone marrow transplantation (BMT)

#### Part A- Acute Radiation Syndrome

##### 1. Introduction

**Acute Radiation Syndrome (ARS)** is an acute illness caused by exposure to a high dose of ionizing radiation, within a short period, to the body. ARS is a deterministic effect of radiation exposure to the whole body or to a significant volume of the body above a threshold of about 1 Gy. This deterministic effect induces a set of clinical and biological manifestations in the organs and tissues affected.

The primary cause is the depletion of immature parenchymal stem cells in vital tissues, leading to damage in multiple organ systems, particularly those with rapidly dividing cells. ARS is most commonly seen following nuclear accidents or radiological events, with the severity of symptoms depending on the radiation dose, duration of exposure, and the area of the body affected. Prompt recognition and management are critical to reducing mortality. Historical examples include

survivors of the Hiroshima and Nagasaki bombings and the first responders at Chernobyl. In severe cases, ARS can progress to radiation-induced multi-organ failure (MOF), which significantly worsens prognosis.

Acute Radiation Syndrome can result from several causes and sources of high-dose radiation exposure. Major sources include nuclear reactor accidents such as Chernobyl and Fukushima, as well as atomic bomb detonations. Orphan sources—uncontrolled or misplaced radioactive materials—also pose a significant risk. Radiological terrorism, such as the use of “dirty bombs,” represents a deliberate source of exposure. Occupational exposure in nuclear industries can lead to ARS if safety measures fail, while medical radiation overdose, though rare, is another potential cause. (refer Table 18.1)

Cause / Source	Example	Probability of ARS
<b>Nuclear reactor accidents</b>	Chernobyl (1986), Fukushima (2011)	Possible in severe exposures
<b>Atomic bomb detonations</b>	Hiroshima and Nagasaki (1945)	High
<b>Orphan sources</b>	Misplaced or uncontrolled radioactive material	Possible
<b>Radiological terrorism</b>	“Dirty bombs” (dispersal of radioactive material)	Very remote
<b>Occupational exposure</b>	Nuclear industry accidents, radiation facility mishaps	Possible
<b>Medical radiation overdose</b>	Accidental therapeutic overexposure (rare)	Rare

Table no. 18.1 Causes and Sources of radiation Exposure

## 2. Radiation Combined Injury, Dose Thresholds, Timing and Delivery

Radiation Combined Injury (RCI) refers to the occurrence of radiation exposure along with trauma, burns, or infection, which significantly worsens prognosis. Acute Radiation Syndrome (ARS) typically develops at whole-body doses greater than 0.7 Gy (70 rads), provided the dose is received in a short time, usually within minutes. Most ARS cases result from external radiation sources, while internal contamination rarely causes ARS. Fractionated or protracted doses, such as those used in cancer therapy, are less likely to induce the syndrome. ARS usually follows high-dose exposure to gamma rays, X-rays, or neutrons, whereas exposure limited to beta radiation tends

to cause localized beta burns or cutaneous radiation injury rather than systemic ARS. For ARS to occur, a large portion of the body must be exposed to doses above 0.7 Gy, even if the exposure is non-uniform.

### 3. Phases of Acute Radiation Syndrome

ARS manifests in distinct phases: a prodromal phase, a latent phase, a manifest illness phase, and finally, either recovery or death. The early recognition of symptoms is essential to initiate timely and targeted intervention.

- **Prodromal Phase:** Nausea, vomiting, fatigue within minutes to days' post-exposure.
- **Latent Phase:** Patient appears relatively well; duration varies with dose.
- **Manifest Illness Phase:** Symptoms depend on affected organ systems (hematopoietic, GI, neurovascular).
- **Recovery or Death:** Based on severity and treatment effectiveness.

The time of onset, type of prodromal symptoms, and their severity are indicators of the radiation dose absorbed and are critical for triage and management.

Prodromal Symptoms	Exposure Dose (Gy)
No noticeable symptoms	<1
Mild nausea, fatigue	1–2
Nausea, vomiting, mild anorexia	2–4
Moderate to severe nausea, vomiting, fatigue	4–6
Severe vomiting, diarrhea, headache	6–8
Immediate vomiting, dizziness, neurological signs	>8

Table no. 18.2 -- Prodromal Symptoms with exposure dose

#### 4. Chronology of Early features

- **Time to Vomiting:** Earlier vomiting after exposure indicates higher dose.

Time to Vomiting After Exposure	Estimated Dose Range (Gy)
No vomiting	<1
≥2 hours	1–2
1–2 hours	2–4
<1 hour	4–6
<30 minutes	6–8
<10 minutes	>8

Table 18.3- Time to Vomiting with estimated dose range

- **Lymphocyte Count Drop:** Rapid decline predicts severity.

This classification helps determine whether a patient can be managed conservatively, requires cytokine therapy and hospitalization, or is likely to progress to severe systemic illness. Dose estimation is best refined with serial lymphocyte counts, but initial decisions are often made based on clinical presentation.

Absolute Lymphocyte Count (/μL)( After 48 hours of exposure)	Severity Grade of ARS
> 1000	Mild

500-999	Moderate
<500	Severe

Table 18.4- Absolute Lymphocyte Count and Severity Grade of ARS

- **Skin Changes:** Erythema or burns indicate localized exposure.
- **Neurological Signs:** Confusion, seizures signal very high exposure.
- **Vital Signs:** Monitor for hypotension, fever, tachycardia.

#### 5. Physical Examination in ARS

- The purpose of the physical examination in Acute Radiation Syndrome (ARS) is to assess the severity and extent of radiation exposure, identify early clinical signs to aid in triage and timely treatment, and guide the need for further laboratory tests and imaging investigations.
- During the initial assessment of Acute Radiation Syndrome (ARS), the focus should be on **vital signs**, including fever, hypotension, and tachycardia, which may indicate systemic involvement. **Neurological status** must be carefully evaluated, as confusion, ataxia, or seizures suggest high-dose radiation exposure and poor prognosis. **Examination of the skin** is also essential, as findings such as erythema, blistering, or dry and wet desquamation may point to localized high-dose exposure.

**Note:** In cases of Cutaneous Radiation Injury (CRI), palpation of erythematous areas may reveal subcutaneous induration or localized warmth, a precursor to radiation necrosis.

System	Key Findings	Interpretation	Approx. Time of Onset
<b>Vital Signs</b>	Fever, hypotension, tachycardia	Systemic involvement, possible sepsis or shock	Hours–Days
<b>Neurological</b>	Confusion, ataxia, seizures	High-dose exposure, poor prognosis	Minutes–Hours
<b>Skin</b>	Erythema, blisters, dry/wet desquamation	Localized high-dose radiation injury	Hours–Days (erythema), Weeks (desquamation)

<b>Hematological</b>	Petechiae, bleeding, pallor	Pancytopenia → Hematopoietic syndrome	Days–Weeks
<b>Gastrointestinal</b>	Nausea, vomiting	GI syndrome (6–10 Gy exposure)	Minutes–Hours (early vomiting), Days (persistent symptoms)
<b>Oral</b>	Mucositis, ulcers	Mucosal damage, part of GI/hematopoietic involvement	Days–Weeks
<b>Pulmonary</b>	Crackles, dyspnoea	Radiation pneumonitis	Weeks–Months
<b>Cardiac</b>	Signs of shock (hypotension, weak pulse, collapse)	Cardiovascular collapse at very high doses	Minutes–Hours
<b>Neurological</b>	Reflex loss, coordination issues, seizures	Neurovascular syndrome	Minutes–Hours

Table 18.5- Initial Assessment of ARS

## 6. Laboratory and Other Investigational Protocols

Laboratory investigations serve two purposes: (1) estimating dose, and (2) guiding organ-specific supportive care.

### Key tests and their significance:

Investigation	Purpose / Interpretation
<b>Lymphocyte Count Kinetics</b>	<ul style="list-style-type: none"> <li>• A rapid fall in lymphocytes is one of the earliest and most reliable indicators of radiation exposure.</li> <li>• ALC &lt; 1200/mm<sup>3</sup> within 24 hours indicates exposure ≥2 Gy.</li> <li>• Serial counts every 6–12 hours help determine exposure trajectory.</li> <li>• Drop &gt;50% in 24–48 hrs indicates high-dose exposure (Andrew’s Nomogram)</li> </ul>
<b>CBC with Differential</b>	<ul style="list-style-type: none"> <li>• Serial counts to monitor lymphocyte depletion</li> <li>• Monitors for pancytopenia — hallmark of hematopoietic syndrome</li> <li>• Neutrophil-to-lymphocyte ratio helps assess immunosuppression severity</li> </ul>

<b>Absolute Neutrophil Count (ANC)</b>	Guides infection risk and need for antibiotics
<b>Platelet Count</b>	Monitors bleeding risk from marrow suppression
<b>Inflammatory Markers : CRP, ESR, Procalcitonin</b>	Detects infection in neutropenic patients
<b>Other investigation protocols:</b>	
<b>Cytogenetic Bio-dosimetry</b>	<ul style="list-style-type: none"> <li>• Dicentric Chromosome Assay to estimate absorbed radiation dose</li> <li>• Gold standard for biological dose estimation.</li> <li>• Performed in specialized labs, results take 48–72 hours but confirm early clinical estimates.</li> </ul>
<b>Bone Marrow Biopsy</b>	Assesses marrow damage in hematopoietic syndrome
<b>Renal / Liver Function Tests and Electrolyte Monitoring</b>	<ul style="list-style-type: none"> <li>• Evaluates dehydration, renal, or organ dysfunction</li> <li>• Important for patients with gastrointestinal losses or systemic shock</li> <li>• Hypokalemia and metabolic acidosis may be seen in GI syndrome or dehydration.</li> <li>•</li> </ul>
<b>Imaging: Chest X-ray / CT Chest</b>	<ul style="list-style-type: none"> <li>• Identifies radiation pneumonitis or infection <ul style="list-style-type: none"> <li>○ Chest X-ray/HRCT: For early detection of radiation pneumonitis.</li> <li>○ Ultrasound abdomen: To assess fluid shifts or GI wall thickening.</li> </ul> </li> </ul>
<b>Whole-Body Counter / Dosimetry</b>	Detects and measures internal contamination if suspected
<b>Stool/Urine Exam</b>	<ul style="list-style-type: none"> <li>• Occult blood indicates mucosal barrier breach</li> <li>• Urine output helps monitor hydration and renal function</li> </ul>

Table 18.6- Laboratory & other Investigational Protocols of ARS

## 7. Management Principles of Acute Radiation Syndrome (ARS)

Management of Acute Radiation Syndrome (ARS) requires rapid recognition, symptom-based triage, and multi-disciplinary coordination to improve survival outcomes. Given the variable presentation depending on radiation dose and route of exposure, care must be individualized and proactive. The following outlines the core principles of ARS management:

### 7.1 Early Triage and Assessment

- Early triage and assessment in radiological emergencies aim to prioritize patients according to the severity of their condition, expected prognosis, and the availability of medical resources.

Symptom-based evaluation plays a central role, with the time to onset of vomiting serving as one of the most useful early indicators—rapid onset typically reflects a higher radiation dose.

- Another important tool is lymphocyte depletion monitoring, as a significant decline in absolute lymphocyte count within the first 24 to 48 hours strongly suggests high-dose exposure and provides valuable prognostic information. Additionally, skin changes such as erythema or burns, along with neurological symptoms including confusion or seizures, may indicate serious localized or systemic radiation injury. Together, these clinical signs help clinicians quickly categorize patients, determine the urgency of interventions, and allocate resources effectively during the early stages of response.
- **Triage Tools:** Triage in radiological emergencies relies on a combination of clinical indicators and diagnostic tools to quickly assess the severity of exposure and guide treatment decisions.
  - Key indicators include the **time to onset of vomiting**, which is a useful early marker of significant radiation exposure, as well as the patient’s **neurological status**, since confusion, disorientation, or reduced consciousness may signal severe injury. **Vital signs**, such as hypotension and tachycardia, provide additional insight into physiological instability and potential complications.
  - **Laboratory tests**, particularly the complete blood count (CBC), are essential for detecting early declines in lymphocyte levels, which correlate with radiation dose.
  - More advanced methods like **bio-dosimetry**, including the dicentric chromosome assay, offer precise estimates of absorbed radiation dose and are invaluable for confirming clinical assessments and planning appropriate medical management. These triage tools together form a comprehensive framework for rapid and effective triage during radiological emergencies.

Symptom/s	Dose	Action required
No vomiting	< 1 Gy	Outpatient with 5-week surveillance
Vomiting in 2-3 h	1-2 Gy	Surveillance in a general hospital (or outpatient for 3 weeks) followed by hospitalization

Vomiting in 1-2 h	2-4 Gy	Hospitalization in a hematological department
Vomiting in < 1 h Diarrhea Erythema	> 4 Gy	Hospitalization in a well-equipped hematological or surgical department with transfer to a specialized center for GFs / BMT

Table 18.7- Guide for management of radiation injuries on the basis of early symptoms

## 7.2 Stabilization of ABCs (Airway, Breathing, Circulation)

- Stabilizing the airway, breathing, and circulation is the first and most essential step in managing patients exposed to radiation, particularly when trauma is also involved.
- **Airway management** includes ensuring that the airway remains open and monitoring closely for any signs of respiratory distress, such as altered breathing patterns, stridor, or obstruction.
- **For breathing**, supplemental oxygen should be administered to correct hypoxia and support adequate ventilation, especially in individuals presenting with inhalation injuries or respiratory compromise.
- **Circulatory support** involves initiating intravenous fluids in cases of hypotension or significant volume loss. This is especially important in patients presenting with features of the gastrointestinal (GI) syndrome of Acute Radiation Syndrome, where severe dehydration and electrolyte imbalance can rapidly develop. Effective ABC stabilization provides the foundation for further management and improves overall patient outcomes.

## 7.3 Decontamination

- Decontamination is a critical step in the management of radiation-exposed patients, aimed at reducing further radiation dose and preventing the spread of contamination to healthcare workers, equipment, and the environment.
- The process begins with the **removal of clothing**, which alone can eliminate up to 90% of external radioactive material.

- This is followed by **skin decontamination**, performed by gently washing the exposed areas with lukewarm water and mild soap to physically remove contaminants without damaging the skin.
- **Abrasive scrubbing must be avoided**, as it can cause skin injury and increase the risk of radionuclide absorption into the body.
- **Special care is required for sensitive areas such as the eyes, ears, nasal passages, mouth, and open wounds, all of which should be irrigated gently** to ensure effective decontamination while minimizing tissue trauma. This systematic approach helps protect both patients and responders while preparing the patient for further medical evaluation and treatment.

#### **7.4 Supportive Care**

- Supportive care is the cornerstone of managing Acute Radiation Syndrome (ARS), as it addresses the widespread systemic effects of radiation injury and helps stabilize patients while specific treatments are initiated.
- Fluid and electrolyte management is especially critical in cases involving the gastrointestinal (GI) syndrome, where severe vomiting, diarrhea, and mucosal injury can rapidly lead to dehydration and hypovolemic shock. Adequate hydration and electrolyte correction are essential to maintain circulatory stability.
- Nutritional support also plays a vital role; when mucositis or significant GI tract dysfunction prevents adequate oral intake, parenteral nutrition becomes necessary to meet metabolic demands and support healing.
- Relief of symptoms is another key component—anti-emetics, anti-diarrheal, and analgesics help reduce discomfort and improve the patient’s overall quality of life.
- Additionally, meticulous temperature and infection control is crucial, as immunosuppression caused by radiation increases vulnerability to infections. Maintaining a thermo-neutral environment and implementing rigorous infection-prevention measures significantly contribute to better outcomes.

#### **7.5 Monitoring and Blood Count Surveillance**

- Monitoring and interpreting laboratory parameters is a critical component of managing patients with radiation exposure, as blood count trends provide valuable insight into the severity of injury and the risk of complications.
  - Serial complete blood counts (CBCs) with differential are essential for tracking lymphocyte, neutrophil, and platelet levels, all of which can decline significantly following radiation exposure.
  - Additional markers such as C-reactive protein (CRP) and procalcitonin help identify emerging infections, which are particularly dangerous in neutropenic patients. Routine renal and liver function tests are also important for detecting systemic organ damage that may result from radiation toxicity or associated trauma.
- The interpretation of these results plays a crucial role in prognosis and clinical decision-making. A drop in lymphocyte count of more than 50% within 24 to 48 hours is a strong indicator of severe radiation exposure and warrants urgent intervention. The development of neutropenia signals a high risk of infection, necessitating early initiation of prophylactic antibiotics and implementation of protective isolation measures. Continuous laboratory surveillance thus provides an essential foundation for guiding treatment strategies and improving patient outcomes following radiological and nuclear emergencies.

## 7.6 Use of Growth Factors and Transfusions

In the management of hematopoietic syndrome, growth factors and transfusions play a crucial role in supporting bone marrow recovery and maintaining adequate blood cell counts. **Granulocyte colony-stimulating factor (G-CSF) and granulocyte-macrophage colony-stimulating factor (GM-CSF)** are used to stimulate the recovery of white blood cells, thereby reducing the risk of severe infections in affected patients. Blood product support, including platelet and red blood cell transfusions, is provided as needed to manage cytopenias and prevent complications such as bleeding or anemia. **In cases where bone marrow damage is irreversible and multi-organ failure is absent, bone marrow transplantation (BMT) may be considered as a definitive therapeutic option to restore hematopoietic function.**

## 7.7 Prophylactic Antimicrobials

Prophylactic antimicrobials are an essential component in the **management of neutropenic or immunocompromised patients, aiming to prevent and treat potential infections**. This includes the use of antibiotics, antifungals, and antivirals, tailored to the patient's risk profile and prevailing pathogens. **Empirical therapy** should be initiated promptly in cases of suspected febrile neutropenia to reduce morbidity and mortality. In addition to pharmacological measures, stringent infection control protocols are crucial, encompassing reverse isolation, the use of personal protective equipment (PPE), environmental controls and strict adherence to hygiene practices to minimize the risk of nosocomial infections.

### **7.8 Nursing & General Care**

Nursing and general care are critical in managing patients at risk of infections, particularly those with neutropenia or compromised immunity. A **high standard of nursing care**, including meticulous aseptic techniques and careful wound management, is essential to prevent secondary infections. **Strict infection-control practices should be maintained, and patients with severe neutropenia may require isolation to minimize exposure to potential pathogens**. Consistent monitoring and adherence to these protocols help ensure patient safety and support overall recovery.

### **7.9 Psychological Support**

Psychological support is a vital aspect of care for patients with acute radiation syndrome (ARS), who may experience intense stress, fear, and trauma due to their condition. **Counseling and psychiatric support** should be made available not only to patients but also to their families, helping them understand and cope with the situation. **Early and ongoing psychological intervention is essential**, as it significantly contributes to long-term recovery, resilience, and the ability to manage the emotional and mental health challenges associated with radiation exposure.

## **8. Clinical Description and Management of Specific Syndromes**

### **8.1 Hematopoietic Syndrome**

Hematopoietic syndrome occurs following whole-body radiation exposure of 1–6 Gy, primarily targeting bone marrow stem cells and resulting in pancytopenia. Clinically, patients may present

with fatigue, increased susceptibility to infections, and bleeding manifestations such as petechiae and bruising. Laboratory findings typically reveal pancytopenia and a hypo-cellular bone marrow. There is often a latency phase lasting several days before symptoms significantly worsen. The prognosis is dose-dependent but can be favorable if the exposure is below 5 Gy and appropriate supportive care is provided.

Management focuses on promoting bone marrow recovery and preventing complications. Growth factors, such as G-CSF or GM-CSF, are administered to stimulate white blood cell production, while infection prevention is achieved through broad-spectrum antibiotics and antifungal prophylaxis. Blood product support with platelet and red blood cell transfusions is provided as needed. Patients require close monitoring, including reverse isolation, serial complete blood counts, and assessment of infection markers. In cases of irreversible marrow failure without multi-organ damage, bone marrow transplantation may be considered as a definitive treatment option.

- ❖ **Radiation Dose:** 1–6 Gy whole-body exposure
- ❖ **Target:** Bone marrow stem cells—leading to pancytopenia.
- ❖ **Symptoms:** Fatigue, infections, bleeding, (petechiae, bruising).
- ❖ **Findings:** Pancytopenia, hypocellular marrow
- ❖ **Latency Phase:** May last several days before clinical signs worsen.
- ❖ **Prognosis:** Dose-dependent; treatable if exposure is <5 Gy with proper care.
- ❖ **Management:**
  - **Growth Factors:** Administer G-CSF or GM-CSF to promote marrow recovery.
  - **Infection Prevention:** Broad-spectrum antibiotics and antifungal prophylaxis.
  - **Blood Support:** Platelet and RBC transfusions as needed.
  - **Isolation & Monitoring:** Reverse isolation, serial CBCs, infection markers.
  - **BMT Consideration:** For patients with irreversible marrow failure and no multiorgan damage.

Box 18.1 - Hematopoietic Syndrome

## 8.2 Gastrointestinal Syndrome

Gastrointestinal syndrome occurs at radiation doses of approximately 6–10 Gy, primarily affecting the rapidly dividing epithelial cells of the gastrointestinal mucosa. Symptoms typically begin within hours of exposure and include nausea, vomiting, and diarrhea. As the mucosal barrier breaks down, patients are at high risk of dehydration, electrolyte disturbances, and bacterial translocation leading to sepsis. Without intensive supportive care, the prognosis is generally poor.

Management focuses on stabilizing the patient through aggressive fluid and electrolyte replacement to prevent shock and renal failure. Symptom control is achieved with anti-emetics and anti-diarrheal, while nutritional support—often through parenteral routes—is provided when oral intake becomes inadequate. Broad-spectrum antibiotics are essential to address sepsis resulting from microbial translocation. Continuous monitoring of vital signs, electrolyte levels, and potential gastrointestinal bleeding is crucial to guide treatment and ensure timely interventions.

- ❖ **Radiation Dose:** 6–10 Gy
- ❖ **Affected Area:** Rapidly dividing cells of the GI mucosa.
- ❖ **Onset:** Nausea, vomiting, and diarrhea within hours.
- ❖ **Complications:** Dehydration, electrolyte imbalance, sepsis.
- ❖ **Prognosis:** Poor without intensive supportive care.
- ❖ **Management:**
  - **Fluid & Electrolyte Replacement:** Prevent shock and renal failure.
  - **Anti-Emetics & Anti-Diarrheal:** Control symptoms and improve comfort.
  - **Nutritional Support:** Parenteral nutrition if oral intake not tolerated.
  - **Infection Control:** Broad-spectrum antibiotics for translocation-induced sepsis.
  - **Monitoring:** Track vital signs, electrolytes, and signs of GI bleeding.

Box 18.2 - Gastrointestinal Syndrome

## 8.3 Cardiovascular Syndrome

At radiation doses exceeding 50 Gy, patients may develop the cardiovascular or circulatory syndrome, which presents rapidly—often within minutes to hours of exposure. Clinical manifestations include hypotension, tachycardia, arrhythmias, and progression to vascular collapse as a result of direct radiation damage to the myocardium, endothelial lining of blood vessels, and autonomic regulatory centers. The prognosis is extremely poor, with death typically occurring within hours to two days despite aggressive intervention.

Management is primarily supportive, focusing on stabilizing hemodynamics through intravenous fluids and vasopressors for severe hypotension. Continuous cardiac monitoring, including ECG evaluation and electrolyte assessment, is essential to detect and manage life-threatening arrhythmias. Oxygen therapy is administered in cases of hypoxia or pulmonary oedema, while pain control and palliative measures are provided to ensure patient comfort in the terminal phase.

- ❖ **Radiation Dose:** >50 Gy
- ❖ **Onset:** Rapid—within minutes to hours after exposure.
- ❖ **Symptoms:** Hypotension, tachycardia, vascular collapse, arrhythmias.
- ❖ **Pathophysiology:** Direct damage to blood vessels and myocardium.
- ❖ **Prognosis:** Poor; often fatal within hours to 2 days.
- ❖ **Management:**
  - **Supportive Care:** IV fluids, vasopressors for hypotension.
  - **Cardiac Monitoring:** ECG, electrolytes, hemodynamic status.
  - **Oxygen Therapy:** If hypoxia or pulmonary oedema present.
  - **Symptom Management:** Pain control and palliative support.

#### Box 18.3 - Cardiovascular Syndrome

### 8.4 Neurovascular Syndrome (NVS)

At extremely high radiation doses of 10 Gy and above, patients may develop the neurovascular or central nervous system (CNS) syndrome, with symptoms appearing almost immediately—within minutes of exposure. Early manifestations include nausea, vomiting, dizziness, and ataxia, which

can rapidly progress to seizures, altered consciousness, and coma. These effects result from direct radiation-induced injury to neurons, disruption of the blood–brain barrier, and severe cerebral edema. The outcome is universally fatal, typically within hours to one or two days, as no therapeutic intervention can reverse the profound neurological damage.

Management is limited to supportive and palliative care. Supportive measures include intravenous fluids and vasopressors for hypotension, while ongoing neurological monitoring helps track the progression of symptoms. Symptom management focuses on controlling seizures with anticonvulsants, providing analgesics, anti-emetics, and ensuring adequate pain relief. Palliative care remains central, prioritizing the patient’s comfort, dignity, and symptom relief in the terminal phase.

- ❖ **Radiation Dose:** at extremely high doses 10 Gy and above.
- ❖ **Onset:** Immediate to within minutes of exposure.
- ❖ **Symptoms:** Nausea, vomiting, dizziness, ataxia, seizures, coma.
- ❖ **Mechanism:** Direct injury to neurons, blood-brain barrier breakdown.
- ❖ **Outcome:** Universally fatal within hours to 1–2 days.
- ❖ **Management:**
  - **Supportive Care:** IV fluids, vasopressors for hypotension
  - **Neurological Monitoring:** Assess consciousness, reflexes, and seizures.
  - **Symptom Management:** Anticonvulsants, analgesics, antiemetic and pain control.
  - **Palliative Measures:** Prioritize comfort and dignity.

#### Box 18.4 - Neurovascular Syndrome (NVS)

### 8.5 Pulmonary Effects – Radiation Pneumonitis

Radiation-induced lung injury generally presents in two forms: acute radiation pneumonitis and late-onset pulmonary fibrosis. Pneumonitis typically develops 1–3 months after exposure and is characterized by symptoms such as cough, dyspnea, chest pain, and fever. The underlying mechanism involves an inflammatory response and injury to the alveolar–capillary membrane,

leading to impaired gas exchange. Risk factors include high-dose radiation exposure, combined injuries, and pre-existing lung disease. Evaluation involves high-resolution CT (HRCT) of the chest and continuous monitoring of oxygen saturation to assess the extent of lung involvement and respiratory compromise.

Management focuses on reducing inflammation, preventing complications, and supporting respiratory function. Corticosteroids are the mainstay of treatment for radiation pneumonitis, helping to decrease inflammatory lung injury. Oxygen therapy is provided for patients with hypoxia, while antibiotics are administered if secondary bacterial infections are suspected. Pulmonary rehabilitation—including breathing exercises and physiotherapy—can help improve respiratory capacity and functional outcomes. Ongoing monitoring with chest imaging and pulmonary function tests is essential to track progression and detect the development of pulmonary fibrosis.

- ❖ **Types:** Acute radiation pneumonitis and late pulmonary fibrosis.
- ❖ **Onset:** Pneumonitis usually appears 1–3 months' post-exposure.
- ❖ **Symptoms:** Cough, dyspnoea, chest pain, fever.
- ❖ **Pathophysiology:** Inflammatory response and damage to alveolar-capillary membrane.
- ❖ **Risk Factors:** High-dose exposure, combined injuries, underlying lung disease.
- ❖ **Investigations:** HRCT chest, oxygen saturation monitoring
- ❖ **Management:**
  - **Corticosteroids:** Reduce inflammation in radiation pneumonitis.
  - **Oxygen Therapy:** Support for hypoxia.
  - **Antibiotics:** For secondary bacterial infections.
  - **Pulmonary Rehabilitation:** Breathing exercises and physical therapy.
  - **Monitoring:** Regular chest imaging and pulmonary function tests.

Box 18.5 - Pulmonary Effects – Radiation Pneumonitis

## 9. Role and Limitation of Bone Marrow Transplant (BMT) in ARS

- ❖ Bone marrow transplantation (BMT) has a limited but important role in the management of acute radiation syndrome (ARS), particularly in cases of severe hematopoietic syndrome where irreversible marrow failure has occurred. It is not broadly indicated and must be considered only under specific clinical circumstances. **Internal radionuclide contamination is a significant contraindication to BMT until effective decorporation has been completed**, as ongoing internal irradiation would compromise transplant success and patient recovery.
- ❖ Allogeneic BMT may be considered only in highly selected cases, particularly when:
  - A fully HLA-matched sibling donor is available, and
  - The patient's absolute lymphocyte count (ALC) falls below 100/ $\mu\text{L}$ , indicating profound marrow failure, and
  - The estimated or presumed radiation dose is in the range of 8–12 Gy, where spontaneous hematopoietic recovery is extremely unlikely.
  - In this dose range, irreversible bone-marrow aplasia typically occurs, and supportive care alone is insufficient for survival.
- ❖ Additionally, the patient should have no other life-threatening injuries, such as extensive burns, that would preclude the success of transplantation or overall survival. It is also essential to ensure that irradiation is not continuing from an internal source before proceeding with BMT.
- ❖ The primary goal of BMT in ARS is to restore functional hematopoiesis in patients who are unlikely to recover bone marrow function on their own, thereby improving long-term survival prospects when other supportive measures are insufficient.
- ❖ In cases where bone marrow injury is potentially reversible, BMT may be counterproductive due to the high risk of graft rejection and transplant-related complications. Evidence suggests that BMT can improve survival only in carefully selected patients with confirmed irreversible marrow failure. Successful use of BMT requires precise timing, rigorous patient selection, and coordination within a multidisciplinary management framework to optimize outcomes.

❖ **Timing of grafting**

- The timing of marrow grafting is crucial and presents a dilemma. Experimental data suggest that the marrow should be infused within the first 3-5 days of radiation exposure. This coincides with the peak period of immunosuppression; and graft rejection, therefore, will be less likely.
- These findings stress the importance of developing reliable clinical and laboratory parameters to assess the degree of radiation damage to the marrow as quickly as possible and to determine which patients should be given marrow transplants.
- Waiting for a week or longer after the radiation exposure would require some form of immunosuppressive treatment to prepare the patient for a marrow graft. Such treatment may be less tolerated by a radiation accident victim. The marrow transplant must be carried out at a treatment facility equipped for such procedures.

❖ **Limitations:** The use of bone marrow transplantation (BMT) in acute radiation syndrome is constrained by several significant limitations, making it suitable only for a narrow group of patients. BMT is effective primarily in carefully selected individuals who have severe hematopoietic syndrome but no other life-threatening injuries; those with multi-organ failure or exposure to very high radiation doses (>10 Gy) derive little to no benefit. The procedure carries substantial risks, including graft-versus-host disease (GVHD), severe infections, and complications related to prolonged immunosuppression. Its feasibility is also dependent on the availability of a compatible donor and accurate HLA typing, both of which can be challenging in emergency scenarios. Additionally, BMT requires extensive supportive care and access to specialized transplant facilities, which may not be readily available in mass-casualty or resource-limited settings. Even when performed under optimal conditions, the prognosis remains guarded, underscoring that BMT is not a universal solution for radiation injury management.

❖ **Medical lessons learned from other radiological accidents:** Medical lessons learned from previous radiological accidents, including the Chernobyl disaster and the Soreq accident, clearly demonstrate that bone marrow transplantation (BMT) plays only a very limited role in

the treatment of radiation accident victims. Evidence shows that BMT benefits only a small and carefully selected subset of patients, and its use must be guided by strict clinical criteria. It may be considered in individuals who have received a uniformly distributed whole-body radiation dose in the approximate range of 8–12 Gy, where spontaneous hematopoietic recovery is unlikely. Candidates must not have severe skin injuries, extensive internal contamination, or significant conventional trauma, as these factors markedly reduce the chances of transplant success and survival. These lessons underscore the importance of accurate dose assessment, comprehensive injury evaluation, and judicious patient selection when considering BMT in radiation emergencies.

## **10. Infection Management**

### **10.1 General Principles**

Radiation exposure leads to profound neutropenia and damage to the mucosal barriers, significantly increasing the risk of sepsis. In this context, febrile neutropenia must always be treated as a medical emergency, as delays in diagnosis or treatment can rapidly lead to life-threatening complications. Early identification, prevention, and prompt management of infections are therefore central to patient care.

Key preventive measures include maintaining strict hygiene and aseptic techniques, ensuring vigilant monitoring for early signs of infection, and educating healthcare workers and caregivers about infection-control practices. Prophylactic antibiotics, antivirals, and antifungals should be used when clinically indicated. Invasive procedures should be minimized to reduce infection risk, while adequate nutritional support helps maintain immune function and mucosal integrity. Environmental controls, such as HEPA filtration and clean-zone protocols, further reduce exposure to pathogens. Continuous reassessment of infection risk ensures that preventive strategies remain aligned with the patient's clinical status.

- ❖ Radiation causes **neutropenia** and **mucosal barrier damage**, increasing the risk of sepsis.
- ❖ **Febrile neutropenia** is a medical emergency.
- ❖ **Early identification** and **prevention of infection** are critical.
- ❖ **Key measures:**
  - Strict hygiene and aseptic techniques.
  - Close monitoring for infection signs.
  - Educating healthcare workers and caregivers.
  - Prophylactic use of antibiotics, antivirals, antifungals when indicated.
  - Minimizing invasive procedures.
  - Maintaining nutritional support.
  - Implementing environmental controls (HEPA filters, clean zones).
  - Regularly reassessing infection risk.

Box 18.6 – General Principles of Infection Management

## 10.2 Infection Control Practices

Infection control practices are essential for protecting neutropenic patients and reducing the risk of life-threatening infections following radiation exposure. Patients should be managed in reverse isolation rooms to minimize microbial exposure, and all caregivers must adhere strictly to personal protective equipment (PPE) protocols. Regular skin assessments and diligent oral hygiene help prevent entry points for infection, while dietary precautions—such as avoiding raw foods, fresh produce, and flowers—further reduce microbial contamination risks. All medical equipment and the patient’s environment should undergo rigorous disinfection, and patient transport should be minimized by establishing clearly defined clean and contaminated zones. When available, HEPA filtration and air purification systems offer additional protection. Proper waste disposal and contamination control procedures must be consistently followed. Ensuring that healthcare workers are well trained in both radiation emergency response and infection control practices is critical. Visitor access should be restricted and carefully screened to prevent unnecessary

exposure. Continuous documentation and monitoring of adherence to infection control protocols are necessary to maintain high standards and safeguard patient outcomes.

- Reverse isolation rooms for neutropenic patients.
- Strict PPE use for all caregivers.
- Frequent skin inspection and oral hygiene.
- Avoid raw food, flowers, and fresh produce.
- Rigorous disinfection of equipment and patient environment.
- Minimize patient transport; establish clean and contaminated zones.
- Use HEPA filters and air purification systems if available
- Proper waste disposal and contamination control.
- Staff training in radiation emergency and infection control.
- Visitor screening and restricted access.
- Document and monitor adherence to infection control measures

Box 18.7 – Infection Control Practices

### 10.3 Preventing Infection in Immunocompromised Patients

Effective infection prevention is a cornerstone of care in patients with radiation-induced neutropenia and immunosuppression. Key preventive strategies include:

Preventive Measure	Details
Hand Hygiene	Frequent handwashing with soap or alcohol-based sanitizers
Protective Environment	HEPA-filtered rooms (Laminar flow); minimized exposure to visitors

Food Safety	Avoid raw or undercooked food; ensure proper washing and cooking; Pressurized cooked food before decontamination.
Personal Protective Equipment	Use of PPE as needed for the allied and healthcare
Immunizations	Administer inactivated vaccines before immunosuppression where possible
<b>Additional Prophylactic Measures</b>	
Antimicrobial Prophylaxis	Bacterial (e.g., fluoroquinolones), viral (e.g., acyclovir), fungal (e.g., fluconazole)
Catheter Care	Use sterile technique to avoid line infections
Oral Care	Prevent mucositis and opportunistic infections
Skin Integrity Monitoring	Prevent breakdown and entry of pathogens
Patient Education	Awareness of hygiene, early signs of infection

Table 18.8- Preventing Infection in Immunocompromised Patients

### 10.5 Management of Infection

Prompt recognition and treatment of infection are critical in patients with radiation-induced neutropenia or immunosuppression. Initial management includes obtaining relevant cultures, such as blood, urine, and wound samples, to identify causative pathogens. Empirical broad-spectrum antibiotics should be initiated within one hour of fever onset; as febrile neutropenia represents a medical emergency. Patients must be closely monitored for early signs of sepsis, including hypotension, elevated C-reactive protein (CRP), and changes in mental status. Supportive care is essential and may include intravenous fluids, supplemental oxygen, and

hemodynamic support to maintain organ perfusion and stabilize the patient while definitive antimicrobial therapy is administered.

#### **10.6 Empirical Therapy for Febrile Neutropenia\***

- ❖ Febrile neutropenia is a medical emergency requiring prompt empirical treatment. Antibiotic therapy should be initiated within one hour of fever onset. Broad-spectrum anti-pseudomonal beta-lactams, such as cefepime or piperacillin-tazobactam, are preferred as first-line agents. Vancomycin should be added if there is suspicion of catheter-related infection, skin infection, or other Gram-positive involvement.
- ❖ Before starting antibiotics, blood cultures should be collected whenever possible to guide subsequent therapy. Vital signs and clinical status must be closely monitored throughout treatment. Antibiotic regimens should be adjusted based on culture results and sensitivity testing. If fever persists beyond 4–7 days, evaluation for fungal infections is warranted, and antifungal therapy should be initiated as indicated.
- ❖ Supportive care, including intravenous fluids and supplemental oxygen, is essential to maintain hemodynamic stability and organ function. Patients should be educated to report fever or other symptoms immediately, and strict infection prevention measures must be maintained throughout therapy to minimize the risk of secondary infections.

- Initiate empirical antibiotic therapy within 1 hour of fever onset.
- Use broad-spectrum anti-pseudomonal beta-lactams (e.g., cefepime, piperacillin-tazobactam).
- Add Vancomycin if catheter-related or skin infection is suspected
- Monitor vital signs and clinical status closely.
- Adjust antibiotics based on culture and sensitivity. (Collect blood cultures before antibiotic administration if possible)
- If fever persists >4–7 days: evaluate for fungal infections; start antifungal therapy as needed.
- Adjust antibiotics based on microbiological data.
- Provide supportive care including fluids and oxygen.
- Educate patients to report fever or symptoms early.
- Maintain infection prevention protocols throughout therapy.

*\*Febrile neutropenia is the presence of fever in a neutropenic patient. It is the most common life-threatening complication of cancer therapy and is considered an oncologic emergency.*

Box 18.7 – Empirical Therapy for Febrile Neutropenia

## 11. Medical follow-up

Survivors of significant radiation exposure require lifelong medical follow-up to monitor for late effects, including secondary malignancies such as leukemia, solid tumors, and thyroid cancer. Follow-up should be tailored to the organs and tissues most affected by radiation, with particular attention to the eyes, thyroid, bone marrow, gonads, skin, and other exposed sites.

Early detection of complications is critical and can be achieved through routine screenings, laboratory tests, and imaging studies, allowing interventions before symptoms develop. Survivors should also receive lifestyle counselling to encourage healthy behaviors that reduce the risk of

secondary diseases and support long-term recovery. Preventive health measures, including regular check-ups and patient education, are essential to identify and manage treatable conditions promptly.

In addition to physical health monitoring, ongoing psychological support is important to address stress, trauma, and anxiety related to the exposure. Occupational rehabilitation should be considered to help survivors return to work safely and maintain quality of life. Comprehensive, multidisciplinary follow-up ensures optimal long-term outcomes for radiation-exposed individuals.

## Part B- Cutaneous Radiation Injuries (CRI)

### 1. Definition

Those accidents in which small areas of the body are subjected to very high doses of ionizing radiation while the rest of the body is exposed only to relatively low doses, and therefore the clinical signs and symptoms characteristic for the acute radiation syndrome (ARS) are usually missing, are referred as local radiation injuries. The clinical picture is usually termed as “cutaneous radiation syndrome” (CRS)/ Cutaneous Radiation Injuries (CRI)

Synonyms of CRI: Radio-dermatitis, Radiation dermatitis, Cutaneous radiation effects.

### 2. Typical Scenarios Leading to Partial-Body Radiation Injuries

Scenario Type	Common Situations	At-risk Persons
<b>Unshielded source due to mis-operation or equipment failure</b>	Industrial radiography devices; medical equipment (Radiotherapy machines); research irradiators	Radiographers, operators, mechanics, medical staff, patients, researchers
<b>Misplaced, lost or stolen sources</b>	Individuals unknowingly handling/dismantling shielded sources	Public, scrap workers, children, untrained adults
<b>Finding lost unshielded sources</b>	Picking up radiography sources, orphan sources, sources in scrap yards	Public, scrap dealers, waste handlers
<b>Intentional incidents</b>	Suicide attempts, criminal use of stolen sources	Specific targeted individuals

Table 18.9- Scenarios leading to Partial Body Radiation Injuries

### 3. Typical Scenarios for local radiation injuries –

- Pocket areas: Found sources are often kept in pockets or close to the body, leading to prolonged exposure.
- Hands and fingers: Handling, dismantling, or inspecting sources without awareness of danger.

Location & Year	Description of Accident	Effects of Radiation Injuries
<b>Tammiku, Estonia (1994)</b>	Source mishandling leading to exposure	1 death from severe radiation burn to thigh; 3 with hand burns
<b>Gilan, Iran (1996)</b>	Industrial radiography incident	Extended radiation burn to chest of one worker
<b>Lilo, Georgia (1997)</b>	Abandoned sources handled by soldiers	Radiation burns on various body parts in 11 soldiers
<b>Istanbul, Turkey (1998)</b>	Mismanaged cobalt-60 source	Mild radiation burn to two fingers of one individual
<b>Yanango, Peru (2000)</b>	Industrial radiography source held against body	Severe thigh radiation burns leading to amputation of both legs

Table 18.10- Examples of Radiation Accidents

#### 4. Common features of local radiation injuries:

Local radiation injuries are the most common outcome of radiation accidents, accounting for more than 90% of reported cases. These injuries typically occur when an individual comes into direct contact with an unshielded radioactive source, resulting in localized high-dose exposure to the skin or underlying tissues. In many such events, Cutaneous Radiation Syndrome (CRS) becomes the most frequent complicating factor associated with Acute Radiation Syndrome (ARS). When the patient first presents, the actual radiation dose is rarely known, as exposure details are often unclear or unavailable.

Radiation dose estimation usually becomes possible in CRS only after the skin lesion has evolved (run its course) over several weeks, requiring the specialists to evaluate the full clinical course. In most cases, a retrospective reconstruction of the accident scenario—based on interviews, environmental measurements, and source characteristics—provides crucial insight into the exposure. The severity of symptoms depends on the degree of severity of radiation-induced skin

injury, which in turn reflects the total absorbed dose, duration of exposure, type of source, and specific body area involved.

### 5. Common Features of CRS – Inverse Square Law

The severity of Cutaneous Radiation Syndrome (CRS) is strongly influenced by the Inverse Square Law, which states that radiation intensity increases dramatically as the distance from the source decreases. This principle explains why even brief, close contact with an unshielded high-activity source can result in severe localized injury. A classic example is the Algerian accident of 1978, in which a lost 925 GBq (25 Ci) Ir-192 industrial radiography source was inadvertently handled. Because the individual held the source at extremely close range, the dose to the hands increased exponentially, leading to severe radiation injuries. This case highlights how critical even a few centimeters of distance can be in preventing catastrophic local tissue damage.

### 6. Differences between Acute Radiation Syndrome (ARS) and Cutaneous Radiation Injury (CRI)

Aspect	Cutaneous Radiation Injury (CRI)	Acute Radiation Syndrome (ARS)
<b>Occurrence</b>	Can occur independently, without ARS	Occurs after whole-body or major body exposure
<b>Radiation Dose</b>	Localized exposures; minimal threshold for skin injury: <b>3–5 Gy</b>	Whole-body dose $\geq$ <b>0.7 Gy</b>
<b>Depth of Penetration</b>	Injury may remain confined to skin; deeper organs spared	High-penetrating dose affects rapidly dividing cells in bone marrow, gut, CNS
<b>Cause</b>	Therapeutic radiation overdose, localized accidents, fluoroscopy overexposure	Nuclear reactor accidents, radiological terrorism, atomic bomb detonations

<b>Clinical Features</b>	Erythema, blistering, dry/wet desquamation, ulceration, necrosis	Hematopoietic, gastrointestinal, cutaneous, and neurovascular syndromes
<b>Confusion in Literature</b>	CRI sometimes incorrectly equated with ARS	CRS/CRI terms occasionally misused interchangeably
<b>Timeline of CRI Manifestations</b>	<ul style="list-style-type: none"> <li>• <b>Early phase (hours–days):</b> Transient erythema, itching, edema</li> <li>• <b>Latent phase (days–weeks):</b> Symptoms may subside temporarily</li> <li>• <b>Manifest illness phase (weeks–months):</b> Persistent erythema, dry/wet desquamation, blistering</li> <li>• <b>Late effects (months–years):</b> Ulceration, necrosis, chronic non-healing wounds, possible carcinogenesis</li> </ul>	No distinct local timeline; systemic prodrome → latent phase → manifest illness depending on dose and organ system involved

Table 18.11- CRI vs ARS

Source: IAEA, Medical Management of Radiation Injuries, Module XI

## 7. Common Sources associated with radiation Injury

Source	Common Uses	Radiation Type	Associated Radiation Injury Risks
<b>Iridium-192 (<sup>192</sup>Ir)</b>	High Dose Rate (HDR) brachytherapy for cervix, breast, prostate cancers	γ-rays and β-particles	Severe local injuries when handled; common source in industrial radiography accidents
<b>Cobalt-60 (<sup>60</sup>Co)</b>	Tele-therapy (external beam radiotherapy); industrial radiography	High-energy γ-rays (1.17 & 1.33 MeV)	Deep tissue injury; severe local burns if source is touched or unshielded

<b>Cesium-137 (<sup>137</sup>Cs)</b>	Radiotherapy, Low Dose Rate (LDR) Brachytherapy	β-particles and γ-rays	Local skin burns; significant contamination risk due to soluble salts
<b>Fission Products (general β-emitters)</b> <i>(e.g., I-131, Sr-90, Cs-137, Xe-133)</i>	Medical use (I-131); industrial applications	Mostly β-emitters (some γ)	Skin β-burns; internal organ deposition (I-131 → thyroid; Sr-90 → bone)
<b>Strontium-90 (<sup>90</sup>Sr)</b>	Older ophthalmic therapy; superficial radiotherapy	Pure β-emitter	High risk of localized skin and tissue damage
<b>X-ray Machines</b>	Diagnostic imaging (X-ray, CT, fluoroscopy); orthovoltage therapy	X-rays	Radiation dermatitis; fluoroscopy-associated skin injuries with prolonged exposure
<b>X-ray Fluorescence (XRF)</b>	Material/elemental analysis	Low-dose X-rays	Very low risk; accidental exposure possible but rare
<b>Cyclotron Products</b> <i>(<sup>18</sup>F, <sup>11</sup>C, <sup>13</sup>N, <sup>15</sup>O)</i>	Production of radioisotopes for PET/SPECT imaging	Positrons (β <sup>+</sup> ) and annihilation photons	Low external hazard; internal hazard only if contamination occurs

Table 18.12- Common Sources associated with radiation Injury

*\*Cyclotrons are particle accelerators that utilize both magnetic and electric fields to accelerate charged particles in a spiral path, primarily for producing medical isotopes and for research in nuclear medicine. These machines are particularly useful for generating radioisotopes for medical imaging and therapies, like PET and SPECT scans, and for research purposes.*

## **8. Penetration of radiation through skin structures**

### **8.1 Interaction with radiation**

#### **❖ Interaction of alpha radiation with living matter**

Alpha radiation is absorbed in superficial layers of dead cells within the stratum corneum.

#### **❖ Interaction of Gamma radiation with living matter**

Gamma radiation damages underlying tissues and organs

#### **❖ Interaction of beta radiation with living matter**

Beta rays can only penetrate a few millimetres of tissue. Beta particle ranges are considerably greater than those for alpha particles. Unlike the interaction of alpha particles with matter, the path of beta particles through matter is not in a straight line. While beta particles may only penetrate a short distance into a medium, their mean path length (the average distance that a beta particle would travel in a medium if its path were straightened out) can be quite long.

In addition to a difference in range when compared with alpha radiation, there is also a significant difference in the pattern of energy deposition.

### **8.2 Cellularity**

Normal human skin demonstrates a uniform, layered cellular architecture beginning with the basal layer. The epidermis has an average thickness of about 70  $\mu\text{m}$ , although basal cells are also found in the hair follicles at a depth of approximately 200  $\mu\text{m}$ . The dermis is thicker, averaging 1–3 mm.

When human skin is exposed to 100–150 Gy of X-rays, significant pathological changes occur. There is a marked reduction in the number of basal layer cells, and the remaining cells appear irregular in both size and shape. Some cells become separated, exhibiting acantholysis, and occasional bizarre mitotic figures may be observed. As the damage progresses, the entire epithelial layer undergoes ulceration and sloughing.

### **8.3 Skin Layers**

The tissue of the skin most sensitive to radiation is the rapidly developing germinal or basal layer of

epithelial cells. In the normal epidermal layer of skin, the cells that make up the basal germinal layer through the superficial layers are uniform in appearance and are well differentiated.

Irradiation damages the moderately radiosensitive basal germinal cells. It disrupts the normal cellular appearance, causes atypical and bizarre cells in the upper layers, and results in a general loss of cohesiveness at the intercellular junction.

## 9. Stages and Grades of CRI

CRI will progress over time in stages and can be categorized by grade.

**Prodromal Stage:**(within hours of exposure): This stage is characterized by early erythema (first wave of erythema), heat sensations and itching that define the exposure area. The duration of this stage is from 1 to 2 days.

- ❖ **Latent Stage (1-2 days' post exposure):** In the latent stage of cutaneous radiation injury (CRI), no visible injury is evident. However, the duration of this period is influenced by both the radiation dose and the body part exposed. Generally, the higher the dose, the shorter the latent period. Moreover, skin sites such as the face, chest, and neck have a shorter latent stage compared with more resistant areas like the palms of the hands or the soles of the feet, where skin is thicker.
- ❖ **Manifest Illness Stage (days to weeks post exposure):** During the manifest stage of cutaneous radiation injury (CRI), the basal layer of the epidermis is repopulated through proliferation of surviving clonogenic cells. This phase typically begins with main erythema (second wave), accompanied by a sensation of heat and mild edema, often with increased pigmentation. The subsequent clinical course depends on the radiation dose: patients may develop dry desquamation, ulceration, or, in severe cases, necrosis.
- ❖ **Third Wave of Erythema (10-16 weeks post exposure especially after beta exposure):** In this stage of cutaneous radiation injury (CRI), the exposed individual may develop late erythema, along with vascular injury, persistent edema, and increasing pain. A characteristic bluish discoloration of the skin may be seen due to compromised circulation. While epilation may

subside at this stage, patients are at risk of developing new ulcers, dermal necrosis, dermal atrophy, and thinning of the dermis, which often result in chronic, non-healing wounds.

- ❖ **Late Effects** (months to years post exposure – threshold dose ~10 Gy or 1000Rads): This is the chronic phase of cutaneous radiation injury, clinical manifestations may range from mild dermal atrophy or thinning of the dermis to more severe complications such as persistent ulcer recurrence, dermal necrosis, and deformity. Progressive vascular damage may lead to occlusion of small blood vessels, causing impaired blood supply, telangiectasia, and regional lymphostasis due to lymphatic network destruction. Long-term sequelae can include invasive fibrosis, keratosis, vasculitis, and subcutaneous sclerosis of connective tissue. Patients often experience pigmentary changes and chronic pain, and in some cases, radiation-induced skin cancer may develop years after exposure.
- ❖ **Recovery** (months to years)

#### 10. Clinical manifestations of Cutaneous Radiation Syndrome

- ❖ Clinical manifestations of Cutaneous Radiation Syndrome (CRS) vary widely and depend on the severity of the radiation-induced skin injury, which itself is influenced by several radiation-related and tissue-related factors. The characteristics of the radiation play a central role: the penetration power and energy determine how deeply the radiation affects skin and subcutaneous layers, while the absorbed dose and dose rate dictate the intensity and rapidity of tissue damage. Fractionation also affects severity, with single high-dose exposures generally producing more pronounced injury than fractionated or prolonged exposures.
- ❖ Equally important are the characteristics of the tissue or organ involved. The structural composition of the skin, along with the radio-sensitivity of specific cell populations, shapes the clinical presentation. Highly sensitive cells in the basal layer of the epidermis are among the earliest to be damaged, leading to erythema and desquamation. Cells lining hair follicles are similarly vulnerable, often resulting in localized hair loss. Damage to endothelial cells and fibroblasts contributes to later manifestations such as oedema, ulceration, and fibrosis. The size of the exposed skin surface also influences the clinical course, as larger areas of injury can lead to more extensive tissue involvement and complicate healing.

Determinants Category	Specific Factors	Influence on Severity of CRS
<b>Radiation Characteristics</b>	• Penetration power (quality & energy of radiation)	Determines depth of tissue injury and extent of basal layer damage
	• Absorbed dose	Higher dose → more severe and deeper tissue necrosis
	• Dose rate	High dose rate → acute and more severe skin reactions
	• Fractionation	Single large dose causes more damage than fractionated exposures
<b>Tissue / Organ Characteristics</b>	• Tissue/organ structure	Complex structures show variable injury across layers
	• Radiosensitivity of cells	Highly sensitive cells (e.g., basal keratinocytes) show early damage
	• Basal layer epidermal cells	Primary target → early erythema, dry/wet desquamation
	• Hair follicle cells	Damage leads to epilation (hair loss) in exposed areas
	• Endothelial cells, fibroblasts	Injury contributes to late effects: edema, ulceration, fibrosis
	• Size of exposed skin surface	Larger area → greater systemic stress and more complex wound evolution

Table no. 18.14- Determinants of Symptom Severity of CRS

- ❖ Cutaneous Radiation Syndrome (CRS) demonstrates both a temporal and dose-dependent response, reflecting the extent of damage to subcutaneous tissues and connective structures. Its manifestations progress in stages, correlating with the absorbed dose.
- **Initial erythema:** The most typical skin reaction is erythema, which may be observed after brief doses over 3 Gy. It is frequent after 5 Gy and constant after 8 Gy. The precocity of its

occurrence is clinically important, since it indicates the intensity of exposure. Initial erythema is due to capillary dilatation caused by histamine releases.

- **Dry squamation**: Within several days, dry desquamation may occur, characterized by scaling and peeling of the epidermis. This arises from diminished mitotic activity in the basal layer (germinative epidermal layer), reduced sebaceous and sweat gland secretion, and vascular damage
- **Erythema proper**: The secondary erythema appears two to three weeks later, generally preceding moist desquamation. This is caused by functional changes at the microcirculatory level with vasodilatation associated with inflammation. This delayed erythema is always associated with chronic evolution and precedes crises of vasculitis and lesion reopening.
- **Moist desquamation**: Severe damage to the vasculature and connective tissue is the cause of moist desquamation or exudative epithelitis. The threshold dose to provoke this type of change is between 15-25 Gy. Intracellular oedema; vesicles coalesce to form bullae exterior to the basal layer; epidermis may slough, exposing the dermal surface, coated with fibrin. It appears during the second or third week after exposure. Its onset is directly related to the intensity of exposure.
- **Blisters**: Blister appear on hands of the person when exposed to gamma rays of 200 to 400 Gy. 3 days after irradiation. 12 days after the exposure, the diffuse sloughing of epidermis occurs.
- **Ulceration and Necrosis**: Ulceration occurs between four to six weeks after irradiation with doses higher than 20 Gy. Necrosis appears days or several weeks after local exposure to over 25 Gy. The ulcer and its natural evolution, necrosis, result from an ischemic process owing to occlusion of the capillaries underlying the lesion as a consequence of the hyperplasia of endothelial cells (obliterative endarteritis), which finally reduces the blood flow and favors formation of micro thrombi.
- **Late effects**: After one year at high doses, dermal atrophy, deep fibrosis, hyperpigmentation and general dryness are seen. At very high doses (several tens Gy), necrotic damage as a result of obliterative endarteritis may cause the eventual loss of limbs or large areas of the skin.

**11. Examination of patients:**

Examination Component	Description / Purpose
<b>History</b>	Detailed patient history including radiation exposure details, duration, and any prior skin conditions.
<b>Symptoms and Physical Findings</b>	Daily registration of clinical course to monitor progression. Used to plot <b>skin reaction curves</b> over time.
<b>Series of Color Photographs</b>	Visual documentation of skin changes for longitudinal assessment and comparison.
<b>Thermography (Infrared and Microwave)</b>	Non-invasive assessment of skin temperature changes indicating inflammation or vascular compromise.
<b>Perfusion Scintigraphy / Cutaneous Laser Doppler</b>	Measurement of <b>skin blood flow</b> to evaluate tissue perfusion and detect early vascular damage.

Table no. 18.15- Examination of patients with CRS

**12. Time of onset of signs and doses:**

Stages/Symptoms	Dose Range (Gy)	Time of Onset
Erythema	3 -10	2-3 wks
Epilation	>3	4-18 days
Dry desquamation	8 -12	25-30 days
Moist desquamation	15 - 20	20 - 28 days
Blister Formation	15 - 25	15 – 25 days
Ulceration within skin	>20	2- 3 wks
Necrosis Deeper penetration	25	3 wks

Table no. 18.16-Time of onset of signs and doses

### 13. Pathophysiology of the CRI:

Pathophysiological Process	Description / Mechanism	Effect / Outcome
Interaction of anti-proliferative and pro-inflammatory processes	Radiation triggers both inhibition of cell proliferation and activation of inflammatory pathways	Impaired tissue regeneration and inflammation
Cytokine and adhesion molecule release	Increased release of IL-1, IL-6, IL-8, EGFr-R, ICAM-1	Promotes inflammation, leukocyte adhesion, and vascular changes
Vascular changes	Dilation of vessels and increased permeability	Edema, erythema, and local tissue damage
Collagen synthesis stimulation	Mediated by TGF- $\beta$	Leads to dermal fibrosis and tissue remodeling
High-dose radiation effects	Induces dermal and subcutaneous fibrosis	Thickening, stiffness, and long-term scarring of skin
Low-dose radiation effects	Induces dermal and subcutaneous atrophy	Thinning, fragility, and delayed tissue healing

Table no. 18.17- Pathophysiology of the CRI

### 14. Diagnostic tools of the CRI

Diagnostic Tool / Method	Purpose / Mechanism	Findings in CRI
Capillary Microscopy	Non-invasive method for qualitative and quantitative evaluation of dermal (stratum papillae) capillaries	<ul style="list-style-type: none"> <li>• <b>Manifestation / subacute stage:</b> Dilated capillaries, edema, neutrophil/eosinophil infiltration.</li> <li>• <b>Chronic / late stage:</b> Smaller, rare capillaries, epidermal atrophy/acanthosis, dermal fibrosis, rare lymphohistiocytic infiltrates, dilated</li> </ul>

		blood/lymph vessels, hypo/hyperpigmentation, loss of skin appendices
<b>Blood Flow Measurements</b>	Assess skin perfusion	Perfusion scintigraphy, Cutaneous Laser Doppler detect regional hypoperfusion or hyperemia
<b>Imaging Techniques</b>	Structural and tissue assessment	CT, MRI to evaluate deeper tissue involvement
<b>Biopsy Analysis</b>	Histological and cellular evaluation	Histochemical and immunocytochemical studies reveal inflammatory infiltrates, fibrosis, vascular changes
<b>Topographic Dosimetry</b>	Reconstruct radiation exposure	Using anthropomorphic phantoms ((real or virtual objects composed of tissue-equivalent materials that aim to provide a realistic and accurate representation of the anatomy and the properties of tissues, organs, and the whole body for use in real and virtual studies carried out in research and daily clinical tasks)to estimate absorbed dose and affected areas
<b>Electron Paramagnetic Resonance (EPR) Spectroscopy</b>	Detects radiation-induced free radicals	Can measure absorbed dose using dental or tissue samples
<b>Infrared / Thermography Techniques</b>	Early detection of inflammation	Elevated temperature detected in irradiated regions before clinical signs appear
<b>Tele-thermography</b>	Non-contact temperature monitoring	Detects elevated temperature in early-stage irradiated skin (e.g., leg, ankle)

<b>Muscle Ischemia / Necrosis Evaluation</b>	Assess deeper tissue damage	<ul style="list-style-type: none"> <li>Thallium (Tl-201), Technetium (Tc)-Methoxy-isobutyl-isomitril (TIBI) scintigraphy: detects regional perfusion abnormalities.</li> <li>Indium (In-111) Antimyosin antibody imaging: predicts skeletal muscle necrosis after 1 month</li> </ul>
--	-----------------------------	--

Table no. 18.18- Diagnostic tools of the CRI

**15. Treatment of radiation Injuries:** There is no uniform or standard treatment has been prescribed in the management of Cutaneous Radiation Injuries. It is basically symptomatic and empirical.

Treatment / Approach	Indication	Application / Dosage	Mechanism of Action	Result / Outcome	Side Effects
<b>Pentoxifylline + <math>\alpha</math>-Tocopherol (Vitamin E)</b>	Radiation fibrosis	Pentoxifylline: 3 × 400 mg orally daily Vitamin E: 1 × 400 mg orally daily Duration: 6–12 months	Inhibition of collagen synthesis	Reduction of radiation-induced fibrosis	Nothing significant
<b>Interferon-<math>\gamma</math></b>	Radiation fibrosis	2–3 × 100 $\mu$ g/week subcutaneously for 6 months	Antagonizes cytokine TGF- $\beta$ , reducing fibrotic signaling	Reduction of radiation fibrosis	Fever
<b>Conservative Therapy (Chronic Stage)</b>	Chronic CRI	<ul style="list-style-type: none"> <li>Topical/systemic retinoids</li> </ul>	Anti-inflammatory, antifibrotic, antioxidant,	Stabilization and partial improvement of	Variable depending on agent

		<ul style="list-style-type: none"> <li>• Systemic interferon gamma (<math>\gamma</math>)</li> <li>• Systemic superoxide dismutase</li> <li>• Systemic pentoxifylline and <math>\alpha</math>-tocopherol</li> </ul>	cytokine modulation	chronic lesions	
<b>Reconstructive / Plastic Surgery</b>	Profound ulcerations, necrosis, or unstable chronic lesions	<ul style="list-style-type: none"> <li>• Excision of lesion + full-thickness skin graft (if vasculature stable).</li> <li>• Myocutaneous or pedicle flap if vasculature compromised</li> </ul>	Surgical replacement of damaged tissue	Restoration of skin integrity, healing of chronic wounds	Surgical risks, graft failure if vascular supply inadequate

Table no. 18.19- Treatment of radiation Injuries (adapted from IAEA)

**16. Two challenging problems for physicians:**

- Determining the extent of the damage and deciding which tissue will inevitably become necrotic.
- Choosing the most suitable moment to perform surgery

## Take Home Message:

- ❖ Early recognition is critical in ARS.
- ❖ Symptom-based triage guides intervention.
- ❖ Multidisciplinary care approach required.
- ❖ Infection management is central in improving outcomes.
- ❖ Supportive care is the cornerstone of ARS treatment.

## References: (Adapted from)

- NDMA Guidelines for Management of CBRN Medical Emergencies.
- Radiation Injury Treatment Network (RITN). “Triage Guidelines for Hematopoietic Syndrome.”
- REMM. Radiation Emergency Medical Management. U.S. Department of Health and Human Services. (<https://www.remm.nlm.gov>)
- IAEA-WHO (2000) How to recognize and initially respond to an accidental radiation injury.
- IAEA-WHO (1998) Diagnosis and treatment of radiation injuries. IAEA Safety Reports Series No:2
- IAEA, Medical Management of Radiation Injuries, Module XI
- IAEA, Diagnosis and Treatment of Local Radiation Injuries, Module XIII
- AFRRRI: The Medical Effects of Ionizing Radiation (MEIR) CD-ROM. Armed Forces Radiobiology Research Institute (AFRRRI), Bethesda, MD, 1999
- Iljin, L.A.ed.: Radiation Medicine (in Russian), Volume 2, IzdAT, Moscow, 2001
- Guskova A.K. ed: Local Radiation Injury in the Population: Diagnosis and Treatment (in Russian), VCMK “Zashita”, Moscow, 2001.

- Darby SC et al. *Circulation*. 2013;127(4):397–405 and Tapio S. *Mutation Research*. 2016;770(Pt B):299–318
- Hall EJ, Giaccia AJ. *Radiobiology for the Radiologist and UNSCEAR 2008 Report, Vol II*

### **Suggested Readings**

- *Medical Management of Radiological Casualties (4th Edition)* – Oak Ridge Institute for Science and Education (ORISE).
- *Radiological and Nuclear Emergencies: Medical Management Guidelines* – World Health Organization (WHO).
- *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards* – IAEA.
- *Radiation Injury Treatment Network (RITN)* – <https://ritn.net>

## Chapter 19

### Combined Trauma Management

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Understand the complexity of combined injuries involving radiation and trauma.
- Identify the treatment priorities for such patients.
- Manage injuries and open wounds in the context of radiation exposure.
- Understand how radiation exposure affects surgery, healing, and systemic recovery.

#### 1. Introduction

##### ❖ Radiation and Trauma – A Dual Threat

In the event of a radiological or nuclear incident, trauma is often not isolated but coupled with various other physical injuries arising from the blast wave, thermal radiation, and radioactive shrapnel. This leads to a complex clinical scenario referred to as combined injuries, where both ionizing radiation and trauma-related pathology interact, resulting in worsened clinical outcomes. Understanding the mechanisms of injury and associated pathophysiological processes is critical to formulating effective triage and treatment protocols.

#### 2. Radiation and Trauma (Combined Injury)

Combined Injury refers to patients who have been exposed to ionizing radiation and also suffer from other injuries such as burns (thermal and/or chemical), blunt trauma, penetrating wounds, or fractures. Triage for a combined injury patient is done in hospital.

❖ **Clinical Importance:** The clinical importance of combined injuries involving radiation exposure lies in their complex and often severe impact on the human body. Radiation significantly

suppresses the immune response. This immunosuppression leads to delayed wound healing, increased susceptibility to sepsis, complicating the recovery periods. When radiation injury occurs alongside trauma, burns, or other physical injuries, the prognosis becomes markedly worse compared to cases involving either trauma or radiation exposure alone.

#### ❖ **Treatment priorities**

In managing casualties during radiological and nuclear emergencies, treatment priorities must follow a structured and logical sequence to ensure optimal outcomes. The foremost priority is ensuring the **safety of responders**, as they cannot provide effective care if they themselves are exposed to unnecessary risks. Once responder safety is secured, attention shifts to **evaluating and treating patients with life-threatening injuries**. Trauma, airway compromise, hemorrhage, burns, or other acute conditions must be managed immediately following standard emergency and triage protocols, as these issues pose the most immediate threat to survival. Only after stabilizing critical injuries should responders proceed to address radiation-related concerns, including **assessing and managing external and internal contamination**, as well as evaluating the degree of radiation exposure. This stepwise approach ensures that lifesaving interventions are not delayed and that radiation issues are addressed systematically without compromising overall patient outcomes.

### **3. Combined Trauma and Radiation: Initial Hospital Management**

- ❖ Early hospital management of patients with combined trauma and radiation exposure requires rapid, structured interventions to stabilize life-threatening conditions. The first priority is a thorough airway assessment, as inhalation injuries can quickly compromise breathing. Signs such as singed nasal hairs, soot in the sputum, facial burns, or a history of being trapped in a confined space should raise suspicion of airway involvement. In such cases, early intubation is recommended to secure the airway before edema develops and makes the procedure more difficult.
- ❖ Fluid Resuscitation: Fluid management is a critical component of care, especially in patients with significant burn injuries. Fluid resuscitation is indicated when burns exceed 15% of the total body surface area (TBSA). The standard approach uses Lactated Ringer's solution at 2 mL/kg per %TBSA, with half the calculated volume administered in the first eight hours

following the injury and the remaining half over the subsequent sixteen hours. Care must be taken in patients with blast lung injuries, where excessive fluid administration can worsen respiratory compromise; hence, over-hydration should be strictly avoided.

- ❖ **Other Key Considerations:** Pain control is essential and typically achieved using narcotics, but in mass casualty situations, clinicians must anticipate and manage the potential strain on pharmaceutical resources. Tetanus prophylaxis should be provided to all patients whose last booster was more than five years ago or whose immunization status is unknown. In cases of deep or circumferential burns, escharotomy (an emergency surgical procedure involving incising through areas of burnt skin to release the eschar and its constrictive effects, restore distal circulation, and allow adequate ventilation) may be required to relieve pressure, facilitate ventilation, or prevent vascular compromise, particularly in the chest and extremities. It also plays a vital role in managing compartment syndrome, where early surgical intervention is crucial to prevent tissue ischemia. (Box 19.1 summarizes the initial hospital management)
- ❖ Figure 19.1 illustrates the ABCDE assessment by Look–Listen–Feel approach, which provides a systematic framework for rapid primary assessment of patients during emergencies. It covers five major domains—Airway, Breathing, Circulation, Disability (Neurological status), and Exposure/Environment—to help healthcare providers quickly identify life-threatening conditions. For the Airway, clinicians inspect for signs of obstruction such as swelling or injury, listen for abnormal sounds like gurgling or stridor, and feel for air movement or crepitus. Breathing assessment focuses on chest movements, respiratory effort, and sounds like wheezing, along with palpation for tenderness or subcutaneous air. Circulation involves evaluating skin color, capillary refill, pulse quality, heart and bowel sounds, and checking for signs of shock or internal injury. Neurological assessment (Disability) includes observing consciousness level, pupil response, limb movements, and assessing orientation, speech, muscle tone, and response to stimuli. Finally, Exposure and Environment requires fully exposing the patient to look for injuries, burns, bleeding, or deformities, while also listening to focused history and palpating for swelling or spinal abnormalities. This structured

assessment ensures early recognition of critical problems and supports timely, life-saving interventions.

- ❖ Another similar approach as shown in the table 19.1 explains how to assess critically ill or injured patients during the **Primary Survey (XABCDE)** highlighting Control of external Hemorrhage immediately.

- ❖ **Initial Hospital Management**
  - Early airway assessment is critical
  - Suspect injury with singed nasal hair, soot in sputum, or confined space exposure
  - Intubate early if inhalation injury suspected
- ❖ **Fluid Resuscitation**
  - Indicated if burns >15% TBSA
  - Lactated Ringers: 2 cc/kg/%TBSA
  - Half in first 8 hrs, rest in next 16 hrs (from time of injury)
  - Caution in blast lung – avoid over hydration
- ❖ **Other Considerations**
  - Pain control with narcotics – anticipate resource strain in mass casualties
  - Tetanus prophylaxis if booster >5 years ago or unknown
  - Escharotomy\* may be needed for full-thickness burns of chest/extremities, Compartment Syndrome

Box 19.1 - Combined trauma and radiation management

Letter	Component	Key Focus
<b>X</b>	<b>eXsanguinating Hemorrhage</b>	<b>Control external hemorrhage immediately</b>
<b>A</b>	Airway	Ensure airway patency, protect cervical spine
<b>B</b>	Breathing	Assess ventilation and oxygenation
<b>C</b>	Circulation	Control bleeding, assess perfusion and shock
<b>D</b>	Disability	Quick neurological assessment (GCS)
<b>E</b>	Exposure/ Environment	Full exposure of patient + prevent hypothermia

Table no. – 19.1 Primary Survey (XABCDE)

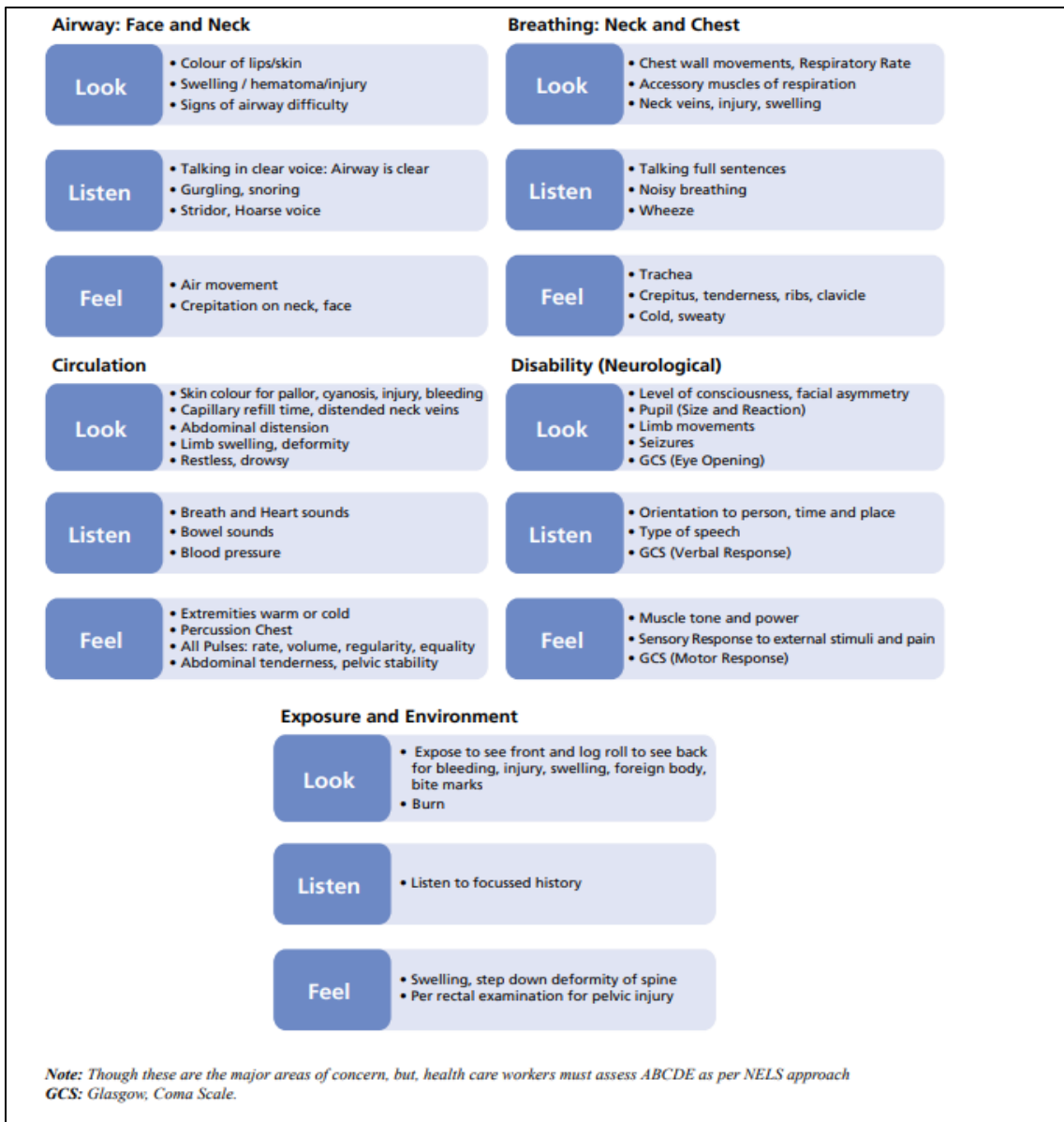


Fig. no. 19.1- ABCDE Assessment by Look, Listen and Feel

**4. Management of Contaminated open wounds:** Open wounds in radiation scenarios must be handled as contaminated until proven otherwise. Improper handling can lead to internal contamination or spread to responder staff.

### Wound decontamination Steps

#### ❖ Preparation for Wound Decontamination

- Clean intact skin adjacent to wound with baby wipe (wipe away from wound)
- Prevents cross-contamination & ensures accurate contamination assessment

#### ❖ Draping

- Apply sterile drapes to isolate wound area and protect uncontaminated regions
- Begin gentle irrigation with sterile saline
- Avoid aggressive flushing to minimize splashing.
- Goal is to remove bulk contamination

#### ❖ Irrigation

- Begin gentle irrigation with sterile saline.
- Avoid aggressive flushing to minimize splashing
- Goal is to remove bulk contamination

#### ❖ Runoff Management

- Use absorbent pads near wound to capture runoff

#### ❖ Post-Decontamination Steps

- Repeat contamination surveys to assess decontamination effectiveness
- Cover wound during drape removal

#### ❖ If Contamination Persists

- Repeat decontamination steps until no further improvement
- If high contamination remains:
  - Explore wound for foreign bodies
  - Perform minor debridement if needed

Box 19.2 - Wound Decontamination Steps

## **5. Management of Radioactive Shrapnel**

Radioactive shrapnel refers to fragments of material—often metallic—contaminated with or containing radioactive substances that become embedded in the body following an explosion, accident, or radiological dispersal event. These fragments act as a localized source of radiation, causing both external exposure to surrounding tissues and internal contamination as radioactive material is absorbed into the body. Because radioactive shrapnel can deliver high, concentrated doses of radiation to nearby tissues and rapidly introduce radionuclides internally, it requires urgent medical attention and careful removal using radiation-safety precautions.

Radioactive shrapnel presents a unique and urgent medical concern during radiological emergencies. Embedded foreign bodies containing radioactive material can lead to significant internal contamination as radioactive substances are rapidly incorporated into surrounding tissues and potentially enter systemic circulation. Therefore, because of this rapid uptake, such cases are considered high priority in emergency management. Visible radioactive fragments—such as metallic shrapnel—should be carefully removed using forceps or other appropriate instruments to minimize further contamination. During the removal process, responders must prioritize their own safety by using long surgical tools that maximize distance from the radioactive source, thereby reducing personal exposure. This combination of prompt removal and radiation safety precautions is essential to protect both the patient and the healthcare provider.

## **6. Timing of life saving early intervention in Radiation exposure**

❖ Timely surgical intervention plays a vital role in both the emergency management and definitive care of patients suffering from combined injuries involving radiation exposure. Since, soft-tissue wounds in irradiated patients are particularly difficult to manage, clinicians often need to consider alternative closure methods such as biological wound coverings or skin grafts to promote healing and reduce the risk of complications. Life-threatening or major injuries should be addressed surgically as early as possible—ideally within the first 36 to 48 hours—since radiation exposure leads to delayed wound healing and places patients at risk of developing granulocytopenia and thrombocytopenia, both of which severely impair the body’s ability to fight infection and control bleeding. In contrast, elective or non-urgent surgical

procedures should be deferred until the late convalescent phase, typically 45 to 60 days after exposure, when hematopoietic recovery has occurred and the patient is better able to tolerate surgical stress and heal effectively

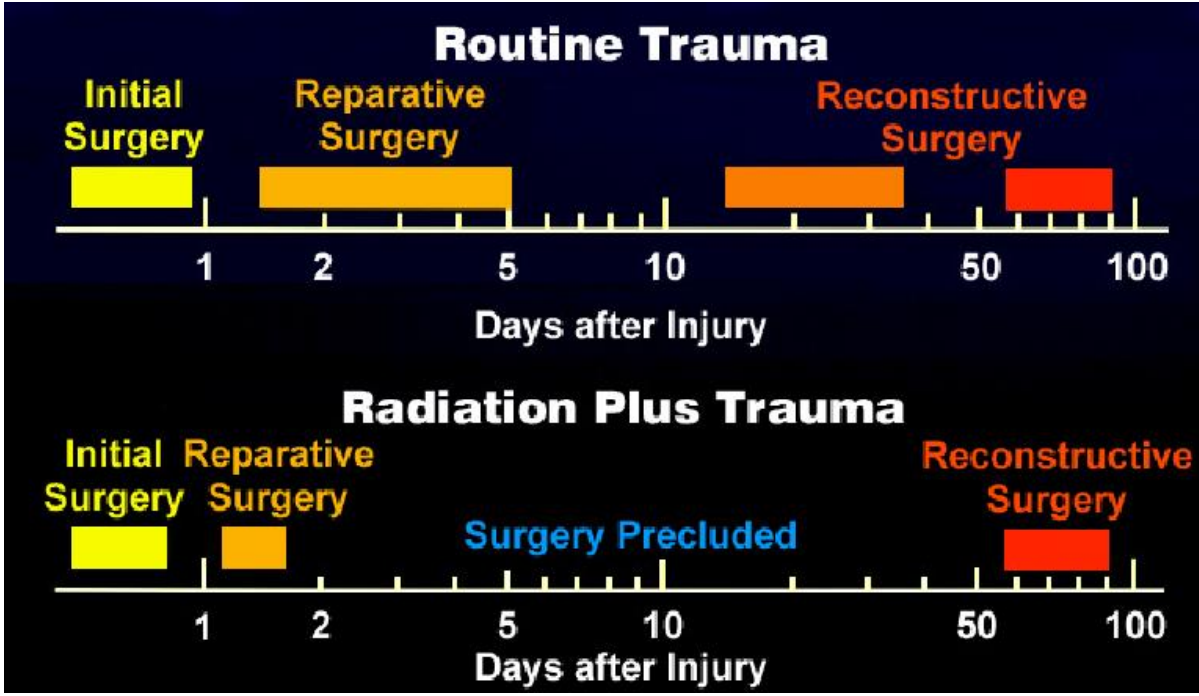


Fig. no. 19.2 – Surgical Timing in routine trauma and radiation plus trauma

❖ **Pre-operative administration of cytokines**

The use of cytokines before surgical intervention plays an important supportive role in managing patients with combined radiation and trauma injuries. The decision to administer cytokines is guided by several factors, including the severity of the traumatic injuries, the degree of radiation exposure, and the availability of medical resources during the emergency response. Cytokine therapy becomes particularly important in patients who are suspected to have received a radiation dose of  $\geq 2$  Gy or who are showing early clinical signs of Acute Radiation Syndrome (ARS), as these individuals are at increased risk of hematopoietic suppression. Agents such as G-CSF (filgrastim) and romiplostim are commonly used to stimulate bone marrow recovery, enhance neutrophil and platelet production, and reduce the risk of infection and bleeding. Administering these cytokines prior to surgery helps improve physiological stability, supports wound healing,

and increases the patient's ability to tolerate operative procedures in the context of radiation-induced marrow suppression.

**7. Blood Products Use and the Radiation Exposure:** Patients with Acute Radiation Syndrome are at risk for post-transfusion graft versus host disease (GVHD). These patients should receive blood products that have been both irradiated and leuko-reduced. If irradiated and leuko-reduced blood is unavailable, then emergency transfusions may still be considered.

**However, decontamination should not delay or impede stabilization of any patient**

### Take Home Message:

- ❖ Complexity of combined injuries: Radiation with trauma (burns, wounds, fractures) leads to more severe clinical deterioration, higher infection risk, delayed healing, and increased mortality compared to trauma alone.
- ❖ Do not delay stabilization of any patient to first perform decontamination.
- ❖ Perform life- and limb-saving tasks before managing radiation problems.
- ❖ Managing injuries & wounds: Clean, decontaminate, and cover open wounds promptly to prevent internal contamination; avoid aggressive procedures initially if the patient is highly irradiated; ensure strict asepsis due to immune suppression.
- ❖ Effect of radiation on surgery & recovery: Radiation exposure delays wound healing, increases bleeding and infection risk, suppresses immunity, and affects organ recovery. Surgical procedures should be timed carefully and kept as conservative as possible until hematologic recovery begins.

**References:** (Adapted from)

- NDMA (2007) Guidelines on Medical Management of CBRN Casualties. (<https://ndma.gov.in/sites/default/files/PDF/Guidelines/medical-preparedness.pdf>)
- REMM (U.S. Department of Health and Human Services) Radiation Emergency Medical Management. (<https://www.remm.nlm.gov>)
- Radiation Injury Treatment Network (RITN) Triage and Management Guidelines. (<https://ritn.net/-/media/project/nmdp/ritn/documents/triage/reacts-prehospital-radiological-triage-poster-2020-march.pdf?rev=27195c78157f4ca7aabeeac169be0c34a&hash=EB542FE8210996288EDE8F7C5A64DD6D>) and (<https://ritn.net/-/media/project/nmdp/ritn/documents/triage/reacts-radiation-patient-treatment-poster-2020-march.pdf?rev=9b8b4ae83fd24c8691c719f36bb448c8&hash=67264845F539F8D99D17488332F3081C>)
- IAEA Safety Standards for Radiation Protection in Emergency Situations. ([https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1578\\_web-57265295.pdf](https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1578_web-57265295.pdf))
- IAEA-WHO (1998) Diagnosis and treatment of radiation injuries. IAEA Safety Reports Series No:2
- IAEA, Medical Management of Radiation Injuries, Module XI
- REMM (U.S. Department of Health and Human Services) Administration for Strategic Preparedness and Response. (n.d.). Radiation Emergency Medical Management (REMM). <https://www.remm.hhs.gov>
- Medical aspects of radiation incidents (4th ed.). Oak Ridge Institute for Science and Education (ORISE), U.S. Department of Energy. <https://www.ornl.gov/reacts>
- Blast injuries. The New England Journal of Medicine, 391(23), e58. (<https://doi.org/10.1056/NEJMvcm2408353>)

- Radiation Injury Treatment Network (RITN). (2021, August). Radiation Injury Referral & Cytokine Administration Triage Guidelines. Retrieved from RITN website (<https://ritn.net/triage>)
- Image Sources:
  - Fig.no. 19.1 (National Emergency Life Support (NELS) Provider course manual for doctors, India)
  - Fig.no. 19.2 (IAEA)

### **Suggested Reading**

- NDMA (2007) Guidelines on Medical Management of CBRN Casualties. (<https://ndma.gov.in/sites/default/files/PDF/Guidelines/medical-preparedness.pdf>)

## Chapter 20

### Group Work-Table Top exercise on RDD/Dirty Bomb

#### Session Objectives:

Upon completion of the group work- table top exercise, the trainee would be able to:

- Understand knowledge/awareness of roles and responsibilities.
- Understand communication mechanism w.r.t. response hierarchy.
- Understand coordination among stakeholders.
- Understand appropriateness of response/decisions

#### Scenario (RDD):

- An explosion occurs in the middle of a crowded bus depot in your district.
- This depot is located close to several markets and residential colonies.
- Within 1 minute of the explosion, the police control room has received an anonymous call.
- The caller claims that the explosion contains Radioactive material.
- The explosion occurred at 10 am on a Sunday, when number of passengers is the highest.

#### Emergency Responses

#### Local Administration

1. Which agencies need to be immediately notified in this scenario?
  - Local police, fire fighters, ambulance (medicos) (if not done already)
  - SDRF/DDRF/NDRF

- CMG-DAE Control Room (DAE ECR)
2. Which agencies can be notified a little later?
    - Various concerned district departments, AERB, MHA
  3. What will be your immediate actions, apart from notification?
    - To coordinate with first responders to take control of incident site
    - To coordinate with nearest hospital to ensure separate rooms are available for handling any contaminated victims from the blast site
    - To put blockade of blast area to stop vehicle movement into and out of blast area to avoid spread of any contamination
    - To set up incident command post (ICP) as soon as feasible
  4. Will you address the media immediately? If so what will you tell them?
    - Media will only be given bare minimum information about the blast
    - No mention should be made about any radiation or radioactivity until verified by monitoring from first responders.
  5. What ground-zero actions would you implement in this incident?
    - First to ensure that victims are immediately treated or removed from the blast site. Dead bodies are not immediate priorities
    - To form respective teams to secure, respond and control the blast site, such as – Security team, Radiation monitoring team, Source recovery team, waste management team, decontamination team etc.
    - To ensure that all public in the vicinity of the cordoned area are informed to stay indoors until advised.
    - To ensure coordination with NDRF time on site and DAE RERC team for technical advisory
  6. Given that a large area is contaminated and several vulnerable assets are present, what administrative actions will you implement?
    - All consumable items within the blast radius and in the down wind direction as advised by DAE-RERC team, to be restricted for consumption until advised.

- All nearby water bodies to be sampled for any contamination by sending out respective teams
  - All nearby areas to be checked for elevated radiation levels from the blast
7. Will you consider evacuating people from the contaminated area?
- Only those within the blast site need to be evacuated.
  - Decision on evacuating people beyond the blast site depends on monitored radiation levels and on advice of DAE-RERC team and CMG-DAE.
8. What will be your message to the media?
- The situation is under control. Teams from NDRF and DAE are at the site. People are requested to stay indoors and take showers. Avoid consuming food from outside until advised.
9. If you have to evacuate the nearby housing societies, how will you plan for it?
- Orderly evacuation as per NDRF procedures.
  - Keeping in mind to cover mouth and nose with handkerchief
  - Evacuees must assemble at a common point at or near their housing society for registration and any contamination checking.
  - Evacuating vehicles must be sanitized once all evacuations are complete.
10. What actions would you take to tackle the issue of contaminated food products in the area?
- Food products and consumable items should be restricted for sale and consumption
  - On the advice of DAE RER team, monitoring of all types of food samples must be done and checked against established levels
  - The scope and extent of restriction should be decided after consultation with civil administration and CMG-DAE
11. What will be your plan of action if buildings and markets have to be bulldozed?
- Established protocols on demolition should be followed.
  - All personnel involved must wear respirators to avoid any potential internal contamination
  - The debris must be monitored and treated as radioactive waste if needed.

12. What message would you give the media about your actions?
  - Any message must be given only after technical details are validated by CMG-DAE
13. How can you plan to deal with possible stigma associated with the affected areas?
  - Public outreach programmes and psychological counselling should be carried out in nearby areas at panchayat level, schools, trade associations etc.
14. What long-term action plan is needed to get the affected area back to normalcy?
  - Long-term follow up of affected victims,
  - A radiation monitoring and sampling programme to be established in affected area to ensure return to normalcy
  - Long-term public outreach is also needed

### **First Responders**

1. Which agencies do you expect to immediately notify you about this incident?
  - Traffic control, DC/DM, concerned public, media personnel etc
2. What are the immediate actions to be performed?
  - To save lives of any victims in the blast vicinity
  - To clear the blast zone of any public to a tentative distance of 400 m and establish an initial cordon
  - To notify all running population to keep calm and move out in an orderly manner with hand-kerchief blocking their nose and mouth
  - To ask public living in the vicinity to take shelter inside their homes/homes/buildings with windows closed
  - To make arrangements for stopping vehicle movement into and out of cordoned area
  - To make arrangements for setting up incident command post (ICP) for incident commander (IC)
  - To make arrangements for arrival of ambulance and fire fighters
  - Fire fighters to fight fire and reduce the spread of water as much as possible to avoid spread of any potential contamination

- NDRF to carry out their standard response protocols for nuclear/radiological emergency.
3. Which agencies will you contact for support in response?
    - Police to take support of NDRF to maintain cordon and any radiation monitoring jobs
    - NDRF to take support of local DAE-RERC team for technical advisory on response
    - Different district departments for support – such as water dept. for water supply to decontaminate, RTO for preventing movement of buses etc.
  4. What logistics would you need to respond to this incident?
    - Police to have MRDS kit ready for deployment upon receiving call of blast
    - NDRF to have nuclear/radiological emergency response kit for response
  5. What instruments and PPEs would you need to respond at the ground-zero?
    - Radiation survey meters, contamination monitors, spectrometer, dosimeters, air samplers
    - Respirators, plastic overalls, boots, gloves
    - Tongs, shielded containers to store radioactive sources, radiation tags, etc
  6. What will you do if you find particles with high radiation levels?
    - First measure the gamma radiation level
    - Mark the location of particles with an identification (card/flag/any other easily identifiable object)
    - Inform the source recovery team about the identification and measured values
  7. What will you do if a civilian in the contaminated area complains about nausea or vomiting?
    - First monitor the person for any external contamination
    - If nothing is found, then take a simple nasal swab and check for internal contamination
    - If nothing, then person may have been externally exposed to gamma radiation, so send him/her for medical examination and follow-up
    - Also remember not to panic the civilian
  8. What will be your plan of action once you identify all hotspots within the cordoned area?

- Mark all the hotspots with identifiable tags
  - Inform the Incident commander about the measured radiation levels and location of tags
  - Source recovery team will recover all the removable hot particles from the locations in their shielded containers
  - Any fixed contamination will be removed by decontamination team/source recovery team
9. How will you ensure safety of your fellow responders?
- Always wear personal dosimeter (both DRD and TLD)
  - Keep monitoring the personal dose levels and inform to IC
  - Adopt the buddy system
  - Always wear appropriate PPEs and remember to check the leak tightness of each other's PPEs.
10. What will you do if a responder's dose levels exceed the planned level?
- If the responder is carrying out lifesaving action and no other manpower is available, then he must be informed about high levels and asked if he wants to continue. If he agrees, then he must be allowed to continue lifesaving action
  - If no lifesaving action is being done, then responder must be recalled by IC and another must be sent in his place
  - The responder must be sent for medical examination and follow-up
11. How can you plan for surveying the large contaminated areas?
- Create radiation monitoring team and split into groups
  - Create a survey route and protocol to follow
  - Use the help of drone-based radiation monitors from DAE
  - If needed, aerial-platform based radiation monitoring systems like AGSS can be used with support from DAE
  - Remember to geo-tag each identified high radiation levels over the area

## Medical

1. What will be your immediate response to this incident?
  - . Inform and alert the Medical personnel and the supporting staff about impending casualties and the identified referral centres.
  - . Ready the Response Team.
  - . Mobilise the resources
  - . Report to the designated Medical post/Decontamination centre.
  
2. What preparation will you make when you are notified about this incident?
  - . Ready the Personnel Decontamination centre.
  - . Ambulance in state of readiness to transfer casualties.
  - . Confirm availability of appropriate PPEs.
  - . Ensure availability of Decontamination agents and Decorporation drugs.
  - . Provision for segregation and disposal of radioactive waste.
  - . Arrange for preliminary investigations like CBC and other baseline investigations.
  
3. How will you know that a patient admitted at the hospital after explosion is contaminated?
  - . External monitoring of patients to confirm radiological contamination and mark Hotspots.
  - . Nasal swab
  - . Whole body monitoring
  - . Radio-bioassay
  - . Relevant pathological investigations
  
4. What actions will you take if a contaminated patient is brought in the hospital?
  - . Prioritise Life-saving actions.
  - . Provide emergency first-aid at the earliest.
  - . Isolate and cover the wounds.
  - . External Contamination-Remove patient's clothes and shoes.
  - . Shower wash with soap, dry and monitor for Hotspots.

- . Decontamination with general basic measures following scrub, rinse, dry and monitor.
  - . Decontamination with specific decorporating agents, particularly contaminated wounds.
  - . r/o Internal Contamination and initiate appropriate Decorporation and Prophylaxis.
5. How will you know that a patient brought to your hospital/health centre from the event location has been exposed to radiation?
- . Clinical Dosimetry: Onset, duration, progress of symptoms and signs like Nausea, Vomiting, Diarrhoea, skin erythema with respect to radiation event.
  - . Investigations: Serial CBC (6 hrly)- drop in Absolute Lymphocyte counts (Andrew's Nomogram).
  - . Biological Dosimetry: CAA, PCC
6. What actions will you take if one of the responders admitted is complaining of nausea and vomiting?
- . Symptomatic treatment, fluid electrolyte correction.
  - . Clinical Dosimetry: Onset, duration, progress of symptoms and signs like Nausea, Vomiting, Diarrhoea, skin erythema with respect to radiation event.
  - . Investigations: Serial CBC (6 hourly)- drop in Absolute Lymphocyte counts (Andrew's Nomogram).
  - . Biological Dosimetry: CAA, PCC
  - . Admission, Isolation, Management, Surveillance and further long term follow-up.

## Chapter 22

### New technological advancements in the medical management of Radiation Emergencies

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Identify emerging technologies used in the diagnosis and management of radiation exposure and contamination.
- Describe advancements in bio-dosimetry, including point-of-care devices and biomarkers, for rapid assessment of radiation dose and biological impact.
- Evaluate the effectiveness of novel therapeutics and countermeasures (e.g., radio protectors, decorporation agents, etc.) in mitigating radiation-induced injuries.

#### 1. RAPID DETECTION OF ABSORBED RADIATION DOSES

##### ❖ Classical Bio-dosimetry Assays

Bio-dosimetry is the measurement of radiation dose received by an individual during the radiation exposure. Biomarkers of ionizing radiation exposure are of great importance for assessing the extent of injury in the event of nuclear incidents or accidental exposure. The estimation of radiation dose exposure is essentially required for therapeutic intervention and also medical management of affected individuals. The gold standard marker for quantification of radiation damage is dicentric assay which is labor intensive and needs high level of technical skills as well as longer time for delivery of the result. It has been the Gold Standard for radiation dose assessment for decades due to its specificity and it has been validated across the globe. Other assays like CBMN and PCC are important for assessing the DNA damage and are recommended by AERB for biodosimetry labs for absorbed dose confirmation and prediction of health problems and its management.

### ❖ **Need for New/Improved Assays for Triage**

Effective medical triage following a mass-casualty radiation accident can potentially save numerous lives. Radiation accident implicit a challenging task for medical responders to triage ionizing radiation-exposed victims into definable, treatment-susceptible groups in a mass casualty scenario. Minimally-exposed (<2 Gy) individuals may not require immediate care, while victims with exposure to moderate (2–6 Gy) or high (6–10 Gy) doses of radiation can most likely benefit from timely treatment. Identifying these subcategories is essential to conserve the scarce resources during any mass casualty scenario. Radiation biomarkers may help to identify individuals requiring urgent medical assessment, optimize resource allocation, and reassure anxious individuals.

For effectively utilizing the available resources, there is an urgent need for developing triage biodosimetry tools for determining the exposure status of an individual. In mass casualty event, existing assays are insufficient due to scalability, speed, and logistical constraints. Ideal triage biodosimetry assays should be:

- **Rapid:** Provide results within hours (preferably <6 hours).
- **High-throughput:** Able to test thousands of individuals per day.
- **Minimally invasive:** Preferably using saliva, urine, or fingerstick blood.
- **Field-deployable:** Point-of-care devices with minimal equipment and training.
- **Robust and reliable:** Resistant to confounding variables (e.g., infection, stress).

## **2. New Assays & Systems developed at INMAS**

At INMAS, we have developed modern and reliable rapid Biodosimetry tools that can be utilized during a mass casualty situation. These assays/ protocols/ systems are summarized below:

### ❖ **Rapid PCE Assay for Detecting Absorbed Radiation Doses**

Micronucleated polychromatic erythrocytes (MN-PCEs) are a biological marker used in radiation biodosimetry. Specifically, the presence of micronuclei (MN) in polychromatic erythrocytes

(PCEs), which are immature red blood cells, indicates DNA damage and can be used to assess radiation exposure.

The frequency or number of MN-PCEs in a blood sample is directly related to the dose of radiation received by the individual. By analyzing the number of MN-PCEs, radiation dose can be assessed.

Peripheral Blood Cytopenia is detected only after continued bone marrow suppression / cell death. Young RBCs in peripheral blood are early indicators of bone marrow suppression & revival of activity. Using microscopy or Flow Cytometry based analysis PCEs can be detected in a drop of blood rapidly, making it an important field-friendly test, useful for triage.

#### ❖ **Gamma H2AX as a biodosimetry tool: Application in Radiological emergency**

An extensive data is available for estimation of  $\gamma$ H2AX protein in radiation damage assessment in various research studies. The linear response of this protein with radiation doses prompted various investigators to use it as a biomarker for radiation biodosimetry purpose. However, the formation of  $\gamma$ H2AX within a minute of the exposure and its measurement using foci measurement or through flow-cytometric techniques makes it a very useful biomarker for dose assessment. The quick estimation of dose in radiation-exposed individual could certainly help in radiation exposure status of an individual. Currently available systems are either bulky or time consuming and also require expertise to carry out the exposure assessment. There is an urgent need for the development of point of care device or a system that could help in detection of an individual exposure to radiation.

This biomarker has also been tested in clinical samples of patients exposed to accidental radiation at Mayapuri, Delhi. Currently efforts are in process to develop a point of care (POC) assay system for radiation triage in case of radiation emergency scenarios using  $\gamma$ H2AX.

#### ❖ **Gene Expression Based 'Field-Use' Assay**

Identification and analysis of radiation-responsive genes and signaling pathways in peripheral blood that have an altered response after radiation exposure is important strategy for triage dosimetry. During an accident, if the blood samples need to reach a distantly located biodosimetry laboratory, optimal storage and transport conditions would be critical for obtaining reliable results.

We developed a simpler protocol utilizing undiluted blood that can segregate the exposed and non-exposed samples in a shorter duration of time. The radiation responsive gene signatures' panel with 19 known radiation responsive genes (*CDKN1A*, *DDB2*, *GADD45A*, *FDXR*, *BAX*, *BBC3*, *MYC*, *PCNA*, *XPC*, *ZMAT3*, *AEN*, *TRIAP1*, *CCNG1*, *RPS27L*, *CD70*, *EI24*, *C12orf5*, *TNFRSF10B*, *ASCC3*) from the putative p53 pathway was optimized for blood transportation conditions (storage temperature and time). 17 out of the 19 genes exhibited a significant upregulation at the optimized conditions. We conclude that sample storage/transport/ post-transit incubation conditions are critical to enhance the sensitivity of gene expression based biodosimetry and facilitate its usage for triage application. The study demonstrates an optimized simpler protocol with strong & reliable radiation responsive gene signatures panel that can be utilized 'on-field' conditions for radiation biodosimetry triage.

#### ❖ **RBC-based Radiation Biomarkers Development**

Red blood cells (RBCs), while traditionally regarded as passive, anucleate carriers of respiratory gases, are now recognized as metabolically active cells capable of dynamic biochemical interactions with their surrounding microenvironment. Recent research underscores their potential role in systemic physiological responses, including those triggered by external stressors such as ionizing radiation. Given the high abundance, long circulation lifespan (~120 days in humans), and ease of isolation of RBCs, they represent a highly accessible and promising target for radiation biomarker discovery. Importantly, their membrane-associated proteome—comprising structural, enzymatic, and transport proteins—is particularly susceptible to oxidative stress and functional perturbations induced by radiation exposure.

We have initiated a focused research program to systematically explore the radiation-induced alterations in the RBC membrane-associated proteins (RMAPs) with the objective of developing reliable protein biomarkers for radiation biodosimetry. Despite the prevalence of RBCs in peripheral blood, the impact of ionizing radiation on their membrane protein landscape has remained largely underexplored. Our research aims to bridge this critical knowledge gap by

investigating how radiation exposure modulates specific RMAPs and leveraging these insights to develop biomarker panels for radiation dose estimation and biological effect assessment.

Using rabbit models of total body irradiation (TBI), our initial experiments employed a combinatorial proteomics approach, integrating two-dimensional gel electrophoresis (2-DE) with shotgun proteomics (LC-MS/MS). This strategy enabled the high-throughput identification of proteins exhibiting statistically significant expression changes across varying radiation doses and post-exposure time intervals. The radiation-responsive RMAPs (RRPs) uncovered in this phase were further subjected to rigorous multivariate analyses, including Principal Component Analysis (PCA), Partial Least Squares Discriminant Analysis (PLS-DA), and hierarchical clustering, to reveal distinct proteomic signatures that correlate with specific radiation dose-time profiles.

To strengthen the translational potential of these findings, we carried out primary data filtering (FDR-adjusted statistical analyses) followed by secondary validation using Western blotting. This led to the establishment of a candidate panel of RMAP biomarkers capable of distinguishing between irradiated and non-irradiated states with high sensitivity and specificity. Several key proteins, including ATP1B1, GAPDH, PRKCB and ANK1, emerged as robust candidates due to their consistent expression trends and functional relevance to erythrocyte integrity and redox homeostasis.

Ongoing efforts at INMAS now leverage label-free quantification (LFQ) and 4D proteomics (incorporating ion mobility separation) to further refine the biomarker panels and enhance detection accuracy. These advanced technologies facilitate deeper proteome coverage, reduced false discovery rates, and more confident identification of low-abundance radiation-responsive proteins.

In alignment with national defense and public health priorities, this research is also oriented toward the development of a portable Field Application Kit for rapid, on-site assessment of radiation exposure in large-scale nuclear or radiological emergencies. Such a tool would be invaluable for first responders, triage officers, and public health authorities, enabling timely decision-making and targeted medical interventions in mass casualty scenarios.

Together, these initiatives position RMAP-based biomarkers as a novel, minimally invasive, and scalable solution for biological dosimetry and radiation injury assessment—ushering in a new paradigm in radiation emergency preparedness and personalized radioprotection strategies.

#### ❖ **NMR Metabolomics Based High Throughput Radiation Bio-dosimetry**

Metabolomics is a high-throughput technology that has great potential for radiation bio-dosimetry that can play an imperative role during the initial triage of radiological disasters to characterize the metabolic status of an individual before the onset of symptoms. Metabolite markers identified through this technique are closely identifiable with real biological end points and provide global systems interpretation of biological effect. Thus, a metabolomics approach could have utility for initial triage after a radiologic or nuclear event, and could comprise one component of a multi-faceted strategy that also involves further assessment of higher risk individuals using other omics measurements as well as standard clinical evaluation.

First and foremost, requirement is to develop a high throughput technique for a quick triage of an exposed population based on a biological dose above or below 2-Gy to determine risk of developing ARS. We have focused to derive metabolic signatures during radiation exposure in biological matrices using metabolomics approach for high throughput radiation bio-dosimetry and further to Predictive modeling system for radiation exposure at preclinical level.

Implemented a non-invasive metabolomics approach for deriving metabolite signatures for high throughput radiation bio-dosimetry. Identified a distinct panel of metabolic markers for triage screening of > 2 Gy segregation of exposed/non exposed population

Accomplished logistic regression-based prediction model classifying radiation exposed and unexposed groups This model on preclinical data represents a proof of concept for screening of radiation exposure during triage. The present findings of our work have provided a strong foundation for the potential application of NMR based metabolomics approach for screening of triage during nuclear accidental scenario. However, limiting the human subjects with radiation exposure mimicking or close to real nuclear accident, the findings need to be scaled up to humans

using advanced mathematical modeling and a combinatorial approach could have utility for initial triage after a radiologic or nuclear event.

#### ❖ **Non-coding RNAs as Radiation Biomarkers**

In recent years, non-coding RNAs (ncRNAs)—especially microRNAs (miRNAs) and long non-coding RNAs (lncRNAs)—have emerged as promising biomarkers of radiation exposure due to their regulatory roles in cellular stress responses and their stability in biofluids.

miRNAs are short, ~22-nucleotide RNAs that post-transcriptionally regulate gene expression by binding to target messenger RNAs (mRNAs). Upon radiation exposure, specific miRNAs are differentially expressed and modulate key pathways involved in DNA damage repair, cell cycle control, apoptosis, and inflammation. For example, radiation-induced upregulation of miR-21 and downregulation of let-7 family members have been consistently observed in multiple models, highlighting their potential as early indicators of cellular damage.

In parallel, lncRNAs, which are longer than 200 nucleotides and often exhibit tissue-specific expression, have been found to orchestrate chromatin remodeling, transcriptional regulation, and post-transcriptional gene expression. Several lncRNAs, such as MALAT1 and HOTAIR, are responsive to ionizing radiation and may serve as functional indicators of radiation-induced genomic instability and cancer susceptibility.

Both miRNAs and lncRNAs can be detected in blood, urine, and other minimally invasive samples, offering significant advantages for real-time monitoring in both clinical and emergency settings. As research continues to uncover their roles in radiation biology, these ncRNAs hold great promise for developing sensitive, specific, and non-invasive biomarkers for radiation exposure and its biological consequences.

### 3. PREPAREDNESS FOR LARGE SCALE EMERGENCIES

#### ❖ Radio protectors & Mitigators

The biological effects of radiation can range from acute radiation syndrome (ARS) to long-term consequences like cancer, organ dysfunction, and genomic instability. To address these risks, extensive efforts have been made to develop radio protectors and radiation mitigators—agents that reduce the harmful effects of radiation on living tissues.

Radio protectors are substances administered prior to radiation exposure with the goal of preventing or reducing initial damage to normal cells. They work by scavenging free radicals, enhancing DNA repair mechanisms, or protecting critical cellular structures. One of the most well-known examples is amifostine, which has demonstrated efficacy in shielding normal tissues during cancer radiotherapy.

In contrast, radiation mitigators are administered after radiation exposure but before the onset of symptoms, aiming to reduce the severity of radiation-induced damage and improve recovery outcomes. These agents often function by modulating inflammatory responses, promoting hematopoietic regeneration, or enhancing tissue repair. Recent research has focused on biologics, such as cytokines, growth factors, and stem cell therapies, as promising mitigators in both medical and emergency contexts.

As the threat of radiological incidents—whether accidental, environmental, or intentional—remains a global concern, the development of effective, safe, and widely accessible radio protectors and mitigators is a public health priority. Ongoing advances in molecular biology, pharmacology, and biotechnology are paving the way for next-generation agents that can be integrated into both clinical practice and national preparedness strategies.

INMAS developed Combinatorial IL6+Zn, fixed dose 5HTP+AET based radio protectors have been successfully tested in small animals. Radio protector N-Acetyl Tryptophan has been successfully tested in NHP. Radiomitigative agents TSA and DAS has been successfully tested in small animals.

#### 4. Radiation Protection, Decontamination and Decorporation

In the event of a radiological or nuclear incident, minimizing radiation exposure and its biological consequences is critical for protecting human health and preserving life. A comprehensive response involves three fundamental strategies: protection, decontamination, and decorporation. Each of these plays a distinct but interrelated role in reducing both external and internal radiation burden.

- ❖ **Protection** encompasses measures taken to prevent or limit exposure to ionizing radiation. This includes time, distance, and shielding principles, as well as the use of personal protective equipment (PPE) and sheltering protocols. Protective actions are vital for first responders, healthcare workers, and affected populations to reduce the risk of acute radiation syndrome (ARS) and long-term health effects. **Protecton is an INMAS developed Radiological Emergency Protective Suit** that is designed for First responders operating in R&N warm zones. It minimizes the adherence of radioactive dust and can withstand up to 20 washings.
- ❖ **Decontamination** focuses on the removal of radioactive materials from the skin, hair, clothing, and surfaces to prevent internal contamination and secondary exposure. Prompt external decontamination—through methods such as gentle washing, removal of clothing, or use of specialized decontaminants—is a cornerstone of early medical management. Proper techniques not only reduce radiation dose but also limit cross-contamination in medical and public health settings. **SHUDHIKA is a buddy care radiological decontamination kit, formulated at INMAS** as per IAEA guidelines. It reduces radiological load on the skin and is field friendly. REMOCON Decontamination Wipes are self-usable and provide a solution for run-off waste.
- ❖ **Decorporation** refers to medical countermeasures aimed at removing or blocking the absorption of internally deposited radionuclides. This includes the use of pharmacological agents such as potassium iodide (KI) for radioactive iodine, Prussian blue for cesium and thallium, and DTPA (diethylenetriamine pentaacetate) for plutonium, americium, and curium. These agents enhance the excretion of radionuclides from the body and are most effective when administered promptly after exposure. **Pru-DeCorp capsules developed by INMAS** are

useful for decorporating radioactive Cs and Tl for first responders entering contaminated zones. These are **40 times cheaper than the available foreign medicine**.

#### Take Home Message:

- ❖ Ongoing advancements in detection technologies, decontamination products, and decorporation therapies are improving the efficiency and effectiveness of radiation emergency preparedness and response worldwide.
- ❖ Rapid detection of absorbed doses: Classical assays (dicentric, CBMN, PCC) are accurate but slow; large-scale emergencies require rapid, high-throughput, minimally invasive, field-deployable bio-dosimetry tools.
- ❖ Need for improved triage assays: Rapid identification of exposure categories (<2 Gy, 2–6 Gy, >6 Gy) is essential for resource allocation in mass-casualty events.
- ❖ Emerging technologies are high-throughput omics, 4D proteomics, portable POC systems, metabolomics platforms, and molecular biomarker panels for rapid dose assessment.

#### References: (Adapted from)

- Gupta M, Srivastava N, Dutta S, et al. Blood biomarkers in metal scrap workers accidentally exposed to ionizing radiation: A case study. *Human & Experimental Toxicology*. 2013;32(12):1311-1322. doi:10.1177/0960327113482477
- Yashavarddhan MH, Shukla SK, Srivastava NN, Suar M, Dutta S, Kalita B, Ranjan R, Singh A, Bajaj S, Gupta ML.  $\gamma$ H2AX formation kinetics in PBMCs of rabbits exposed to acute and fractionated radiation and attenuation of focus frequency through preadministration of a combination of podophyllotoxin and rutin hydrate. *Environ Mol Mutagen*. 2016 Jul;57(6):455-68. doi: 10.1002/em.22027.
- Yashavarddhan MH, Shukla SK, Chaudhary P, Srivastava NN, Joshi J, Suar M, Gupta ML. Targeting DNA Repair through Podophyllotoxin and Rutin Formulation in Hematopoietic

Radioprotection: An in Silico, in Vitro, and in Vivo Study. *Front Pharmacol.* 2017 Oct 31;8:750. doi: 10.3389/fphar.2017.00750.

- Bhagi S, Chandna S. A simplified protocol for gene expression-based biological dosimetry using peripheral whole blood. *Int J Radiat Biol.* 2023;99(11):1692-1701. doi: 10.1080/09553002.2023.2231531. Epub 2023 Jul 12. PMID: 37436720.
- Mukherjee, P., Kumar, K., Babu, B., Purkayastha, J., & Chandna, S. (2023). Alterations in the expression pattern of RBC membrane associated proteins (RMAPs) in whole body  $\gamma$ -irradiated Sprague Dawley rats. *International Journal of Radiation Biology*, 99(11), 1724-1737.
- Purkayastha, J., Grover, P., Mukherjee, P., Kumar, K., & Chandna, S. (2023). Identification of radiation responsive RBC membrane associated proteins (RMAPs) in whole-body  $\gamma$ -irradiated New Zealand white rabbits. *Biotechnology reports (Amsterdam, Netherlands)*, 37, e00783. <https://doi.org/10.1016/j.btre.2023.e00783>.
- Kumar R, Kumari P, Gaurav N, Kumar R, Singh D, Malhotra P, Singh SK, Bhatta RS, Kumar A, Nagarajan P, Singh S, Dalal N, Roy BG, Bhatt AN, Chandna S. N-acetyl-L-tryptophan provides radioprotection to mouse and primate models by antagonizing the TRPV1 receptor and substance P inhibition. *Int J Radiat Biol.* 2025;101(2):118-143. doi: 10.1080/09553002.2024.2435330. Epub 2024 Dec 16. PMID: 39680789.
- Neeraj Kumari, Asmita Das, Anant Narayan Bhatt, Interleukin-6 confers radio-resistance by inducing Akt-mediated glycolysis and reducing mitochondrial damage in cells, *The Journal of Biochemistry*, Volume 167, Issue 3, March 2020, Pages 303–314, <https://doi.org/10.1093/jb/mvz091>
- Dahiya A, Sharma S, Agrawala PK, Dutta A. Histone deacetylase inhibitor, Trichostatin A mitigates ionizing radiation induced redox imbalance by regulating NRF2/GPX4/PINK1/PARKIN signaling in mice intestine. *Mol Biol Rep.* 2024 Aug 29;51(1):943. doi: 10.1007/s11033-024-09867-x. PMID: 39198316.

### **Suggested Reading**

- IAEA (2025) Prepared to respond to nuclear and radiological emergencies (<https://www.iaea.org/bulletin/66-4>)

- WHO (2024) Enhancing radiation safety culture in health care: guidance for health care providers (<https://www.who.int/publications/i/item/9789240091115>)

### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- The concept and importance of psychosocial support
- Core principles of psychosocial support
- Impact of radiological emergencies on mental health
- Normal and abnormal reactions among survivors
- Vulnerable populations
- Psychosocial first aid
- Psychosocial support techniques
- Caring for carers: self-care strategies

## Chapter 23

### Psychosocial Support in Management of Radiation and Nuclear Emergencies

#### 1. Introduction

The landscape of radiological and nuclear emergencies presents unique challenges that extend far beyond immediate physical health concerns. The health impact of these emergencies can persist for decades, creating a complex web of physical, psychological, and social consequences that require comprehensive understanding and intervention strategies. Empirical evidence from past radiological and nuclear accidents has consistently demonstrated a critical finding: the mental

health and psychosocial consequences frequently outweigh the direct physical health impacts of radiation exposure.

This phenomenon has profound implications for emergency preparedness, response, and recovery efforts. While international radiation emergency preparedness and response standards have established provisions for mitigating these effects, there remains a significant gap in practical guidance specifically addressing the mental health and psychosocial aspects of radiation emergencies.

The complexity of individual and community mental health and psychosocial well-being during and after radiation emergencies stems from multiple interconnected factors. Fear and uncertainty about radiation risks emerge as common denominators across affected populations. These concerns are often amplified by the invisible nature of radiation, creating a unique psychological burden distinct from other types of disasters where the threat is more tangible and immediate.

Emergency protective actions, while designed to safeguard human lives, can paradoxically contribute to psychological distress. Interventions such as iodine thyroid blocking, radiation monitoring and decontamination procedures, screening protocols, food and drinking-water restrictions, sheltering in place, and evacuation orders can create additional layers of stress and anxiety among affected populations. The very measures intended to protect may inadvertently become sources of trauma and psychological burden.

Furthermore, the tendency for individuals to associate various somatic illnesses with radiation exposure can lead to overwhelming demand on unprepared health systems. This phenomenon, often referred to as the "worried well" syndrome, can strain healthcare resources and create secondary psychological impacts on both patients and healthcare providers.

## **2. What is psychosocial support?**

The International Federation's Psychosocial Framework (2005-2007) defines psychosocial support as "a process of facilitating resilience within individuals, families and communities." This definition encompasses enabling families to recover from crisis impacts while building capacity to manage future challenging events. The approach fundamentally respects the independence, dignity, and

existing coping mechanisms of individuals and communities while promoting the restoration of social cohesion and infrastructure.

The underlying philosophy emphasizes empowerment of affected populations to care for themselves and each other. When individuals and communities develop enhanced self-confidence and access to resources, they demonstrate improved recovery trajectories and increased resilience for future challenges. This empowerment model represents a fundamental shift from dependency-based approaches to those that build on existing strengths and capabilities.

Psychosocial support functions along both preventive and curative dimensions. In its preventive capacity, it reduces the risk of developing significant mental health problems by addressing risk factors early and building protective factors. In its curative function, it assists individuals and communities in overcoming and managing psychosocial problems that emerge from crisis-related shock and trauma. These complementary aspects work together to build comprehensive resilience that serves populations both in immediate recovery and in preparation for future challenges.

The Inter-Agency Standing Committee (IASC, 2021b) provides additional clarity, noting that while no universally agreed definition exists, practitioners commonly use the term 'psychosocial' to describe the dynamic interaction between social and psychological aspects that contribute to overall well-being. Social aspects encompass interpersonal relationships, social connections, available social resources, prevailing social norms and values, social roles, community life, and spiritual and religious dimensions. Psychological aspects include emotions, thoughts, behaviors, knowledge base, and coping strategies.

### **3. Importance of psychosocial support**

Crises fundamentally disrupt human life across multiple domains, creating cascading effects that extend far beyond immediate physical impacts. Understanding these disruptions provides essential context for appreciating why comprehensive psychosocial support is not merely beneficial but absolutely necessary for effective emergency response and recovery.

The losses experienced during crises are multifaceted and profound. Individuals may lose near and significant loved ones, creating grief reactions that require specialized attention and support. Loss of control over one's life and future generates feelings of helplessness and uncertainty that can persist long after the immediate crisis has passed. The fundamental sense of security that underpins daily functioning may be severely compromised, requiring deliberate efforts to rebuild trust and confidence.

The crucial role of psychosocial support services becomes particularly evident in crises involving large populations. These services address the needs of the majority of affected populations, not just those with the most severe reactions. By providing broad-based support, these services contribute significantly to overall recovery processes while simultaneously reducing the likelihood of developing more serious mental health problems.

This approach also contributes to broadening outreach services while reducing the burden on healthcare systems that may already be overwhelmed by crisis-related demands. Psychosocial support services serve a critical triage function, identifying individuals who require specialized mental health interventions while providing appropriate support for the broader affected population.

#### **4. Core principles of psychosocial support**

Psychosocial support focuses on promoting well-being by addressing both psychological and social needs. The foundation of effective psychosocial support rests on key principles including safety, calming, self- and community efficacy, social connectedness, and hope. These principles guide interventions aimed at strengthening resilience, fostering positive coping mechanisms, and promoting overall well-being in individuals and communities.

- ❖ **Safety** forms the cornerstone of all psychosocial interventions. Creating a secure and stable environment is paramount, minimizing potential threats and promoting both physical and emotional safety. Without this fundamental foundation, other therapeutic interventions cannot take root effectively.
- ❖ **Calming** involves reducing anxiety and distress through various evidence-based techniques. This includes providing clear and accurate information, teaching relaxation exercises, and

promoting a sense of control over one's circumstances. The calming principle recognizes that heightened stress responses can impair an individual's ability to process information and make decisions.

- ❖ **Self- and Community Efficacy** centres on empowering both individuals and communities to believe in their ability to cope with challenges and recover from adversity. This principle emphasizes building confidence in personal and collective capabilities, fostering a sense of agency that is crucial for long-term recovery and resilience.
- ❖ **Social Connectedness** addresses the fundamental human need for meaningful relationships and social support networks. By fostering these connections, psychosocial support combats isolation and promotes a sense of belonging, which research consistently shows as protective factors against psychological distress.
- ❖ **Hope** involves cultivating optimism and a positive outlook for the future, encouraging individuals to envision possibilities for improvement and recovery. This principle recognizes that hope is not merely wishful thinking but an active cognitive process that motivates goal-directed behaviour and sustained effort toward recovery.

## **5. Impact of radiological emergencies on mental health:**

### ❖ **Mental Health Impacts**

The mental health consequences following radiological and nuclear emergencies are extensive and multifaceted. Affected populations experience elevated rates of anxiety disorders, depression, post-traumatic stress disorder (PTSD), and general psychological distress. Sleep disturbances become prevalent, significantly affecting recovery processes and overall functioning. As individuals struggle to cope with overwhelming stress and trauma, substance abuse rates often increase, creating additional health complications and social challenges.

Social consequences further amplify individual distress through disrupted social support networks, reduced healthcare accessibility, and loss of community connections. These social disruptions create additional psychological stress while simultaneously reducing the very resources communities need for effective coping and recovery. The interconnected nature of these physical, psychological, and social effects creates complex clinical presentations that require comprehensive assessment and intervention strategies rather than single-focused approaches.

### ❖ **Fear and Anxiety Related to Radiation Exposure**

Radiation exposure generates unique and particularly intense fear and anxiety due to several distinctive characteristics that differentiate it from other environmental hazards. The invisible nature of ionizing radiation creates fundamental uncertainty that pervades all aspects of the emergency response and recovery process. Individuals cannot independently assess their safety status, determine contamination levels, or evaluate ongoing risk without specialized equipment and expertise. This uncertainty persists throughout emergency and recovery phases, creating sustained psychological stress that may continue for years after the initial incident.

Limited public knowledge about ionizing radiation, its health effects, and measurement methods significantly amplifies anxiety following potential or actual exposure incidents. This knowledge gap frequently extends beyond the general public to include government officials and even some healthcare providers, creating additional uncertainty in official communications and emergency response efforts. The resulting information vacuum is often filled with misconceptions, rumors, and fear-based assumptions that substantially exacerbate psychological distress throughout affected communities.

Negative public perception of radiation exposure connects historically to nuclear weapons use in Japan in 1945, with associated images of death and devastation creating lasting psychological associations that influence contemporary responses. More recent nuclear power plant emergencies, including Chernobyl and Fukushima, have reinforced these negative associations and contributed to widespread fear. Popular culture, including films and media representations, often emphasize dramatic negative outcomes while providing little balanced information about actual risks or protective measures.

### ❖ **Stress Exposure and Behavioural Impacts**

Severe stressors, including disasters and catastrophes, represent significant risk factors for developing long-term mental health conditions including anxiety disorders, mood disorders, acute stress reactions, and complicated grief responses. However, substantial differences exist between

natural disasters and nuclear accidents regarding psychosocial impact, influenced by factors including the extent of human and material losses, psychological acceptance of the event, community cohesiveness, social stigma, and media influence patterns.

Behavioural changes commonly occur during stressful emergency situations, with substance abuse trends often increasing as individuals attempt to cope with significant stress and associated symptoms including depression, anxiety, and PTSD. This pattern appears particularly pronounced among those affected by nuclear accidents, possibly due to the sustained nature of stress and uncertainty characteristic of these events compared to other types of disasters.

## 6. Normal and abnormal reactions to disaster

Understanding typical reaction patterns following radiological and nuclear emergencies enables healthcare providers to distinguish between normal stress responses and indicators of more serious psychological problems requiring specialized intervention. Reactions follow predictable patterns over time, though individual variations exist.

### ❖ IMMEDIATE PERIOD:

- **Normal Reactions** in the immediate period center around **outcry** – initial reactions characterized by intense emotions including fear, sadness, or anger. These reactions represent normal responses to abnormal situations and typically serve adaptive functions by mobilizing individual and community resources for survival and initial coping.
- **Abnormal Reactions** during this period include **overwhelmed states** where individuals become consumed by immediate emotions, demonstrating behaviors such as excessive crying, shock responses, or physical collapse. These reactions indicate that normal coping mechanisms have been exceeded and require immediate supportive intervention.

### ❖ ONE TO TWO WEEKS POST-EVENT:

- **Normal Reactions** during this period often involve **denial** mechanisms where individuals may avoid or refuse to acknowledge traumatic events. This psychological defense temporarily shields individuals from overwhelming memories and emotions, providing time for gradual processing and integration of traumatic experiences.

- **Abnormal Reactions** include persistent **panic or exhaustion** states where high-intensity emotions continue without natural resolution. These sustained reactions may lead to physical exhaustion and indicate need for professional assessment and intervention to prevent progression to more serious conditions.

❖ AROUND SIX MONTHS:

- **Normal Reactions** at this timeframe involve **intrusion** experiences where unbidden thoughts or images of traumatic events begin resurfacing. This represents a normal part of psychological processing as defense mechanisms naturally relax and individuals begin integrating traumatic experiences.
- **Abnormal Reactions** include **extreme avoidance** behaviors such as substance abuse to numb psychological pain. These behaviors indicate difficulty processing trauma and suggest need for specialized mental health intervention to address underlying traumatic stress.

❖ BEYOND SIX MONTHS:

- **Normal Reactions** involve **working through** processes as individuals face the reality of their experiences and begin processing and integrating traumatic events. This phase represents movement toward acceptance and reconstruction of meaning and purpose following trauma.
- **Abnormal Reactions** include **flooded states** where intrusive thoughts and distressing images continue overwhelming normal cognitive functioning. These persistent symptoms may indicate development of chronic PTSD or other trauma-related disorders requiring specialized treatment.

❖ LIFE-LONG PATTERNS:

- **Normal Reactions** involve **adjustment** to new normal circumstances, resuming life activities while carrying memories of traumatic events without allowing them to overpower daily functioning. This represents successful integration of traumatic experiences into ongoing life narrative.
- **Abnormal Reactions** may include **psychosomatic responses** where physical symptoms arise without medical basis, manifesting as bodily complaints due to psychological stress.

**Character distortions** may develop, involving personality alterations including heightened irritability, emotional detachment, or excessive dependency. **Post-Traumatic Stress Disorder (PTSD)** may emerge as a chronic condition. **Dissociative reactions and depression** may develop as persistent psychological conditions requiring ongoing professional treatment.

## **7. Vulnerable populations:**

Vulnerability assessment requires comprehensive understanding of factors that increase risk for adverse outcomes during radiological and nuclear emergencies. Vulnerable populations include individuals living with physical, social, or mental disadvantages who may be unable to meet basic needs and therefore require specific assistance.

In emergency settings, populations such as children, elderly, pregnant women, Individuals with pre-existing trauma or mental health conditions and Individuals with disabilities face additional challenges and barriers that limit their access to services and restrict their participation in emergency responses. These challenges include limited access to modern communication devices and consequent restricted access to key information in accessible formats and languages. Inaccessible transportation systems and emergency plans that lack inclusive design create additional barriers.

## **8. Psychological first aid (PSFA)**

Psychological First Aid represents a foundational intervention providing humane, supportive, and practical assistance immediately following disasters. PSFA involves providing support, assessing needs and concerns, helping people meet basic needs, listening and comforting individuals, helping people feel calm, connecting people to information and services, providing social support, and protecting people from further harm.

### **❖ Implementation Settings**

PSFA can be provided in any safe setting where privacy and confidentiality can be maintained. Flexibility in location allows providers to meet individuals where they are most comfortable and

accessible, whether in shelters, healthcare facilities, community centers, or other appropriate venues.

#### ❖ **Target Population**

PSFA is appropriate for people experiencing distress and requiring support following crisis events. This broad definition recognizes that crisis reactions occur across wide population spectrums and that early supportive intervention can prevent progression to more serious psychological problems.

#### ❖ **Timing and Duration**

PSFA is provided during or immediately after crisis events and may continue for days or weeks depending on emergency severity and individual needs. The flexible duration allows providers to adjust interventions based on evolving circumstances and individual recovery patterns.

#### ❖ **CORE STRATEGIES**

The World Health Organization identifies four fundamental first aid strategies that guide effective service delivery:

- **PREPARE**

**Preparation** involves understanding people and situations specific to particular disasters. This includes understanding biopsychosocial factors that create vulnerability to specific disaster types, locating survivors in disaster areas, and identifying resources within affected communities. Effective preparation requires advance training and planning that enables rapid, appropriate response when emergencies occur.

- **LOOK**

**Assessment** focuses on immediate emotional reactions, physical health issues, psychosocial needs and concerns, availability of family support, availability of local and community resources, and strengths of survivors, families, and communities. This comprehensive assessment provides foundation for appropriate intervention planning.

- LISTEN

**Active listening** involves attending to individual needs and concerns, acknowledging existing strengths, normalizing feelings and thoughts, providing reassurance, ensuring safety, and addressing basic needs. Effective listening creates therapeutic relationships that facilitate recovery and builds foundation for further intervention if needed.

- LINK

**Connection** involves linking survivors to primary caregivers or loved ones, connecting individuals to safe shelter and basic needs resources, and connecting people to appropriate care facilities based on biopsychosocial concerns. This may include connecting individuals with mental illness to district mental health programs, unaccompanied children to child protection agencies, and individuals with sensory impairments to appropriate assistive services.

## 9. Psychosocial support techniques

Disasters create fundamental imbalance among individuals, families, and communities, leaving people in states of confusion while actively seeking support. Providing appropriate help for disaster survivors requires systematic application of evidence-based psychosocial support techniques. Ten essential techniques facilitate effective helping processes and can be practiced by individuals assisting disaster-affected populations.

### ❖ SPECIFIC TECHNIQUES:

- **Ventilation:** Disaster minimizes individuals' coping abilities and resources. Individuals generally suppress their strong negative emotions. These pent-up emotions and feelings get bottled up and affect the well-being of the individual. Channels need to be created for individuals to ventilate their emotional distress that would help in preventing emotional explosion. Creating space for the disaster survivor to talk about his/her negative emotions is like a whistle in a pressure cooker. The whistle regulates the pressure and if a whistle is absent, the pressure cooker might explode. The ventilation process facilitated by the caregiver would act as a safety valve for the survivor to release his/her negative emotions.

Timely expression of traumatic experiences, through talking, facilitate faster recovery and prevent development of mental health complications. Sharing of disaster specific experiences can happen individually or in groups. Individuals should not be forced to talk but s/he should know that there are people or facilities available for individuals to talk about their trauma. During the catharsis (venting of negative emotions) through crying or talking or other acceptable ways of expressing crisis, the caregiver should not interrupt or ask the person to stop crying or talking.

- **Active listening:** People affected by disasters want to be heard and opportunities need to be created for disaster survivors to vocalise their feelings and emotions. Some of the barriers to active communication are lack of privacy, noisy environment, preoccupation of the care provider, poor help seeking behaviour among the survivor, negative attitude of the care provider and lack of training in the helping process. The SLOWER technique helps in motivating the survivor to talk about the negative experiences. S – Sitting squarely L– Leaning forward O – Openness W– Withhold your judgement E – Eye-to-eye contact R – Relaxed posture.

To make the individual know that s/he is being listened, the caregiver can paraphrase periodically, can ask whether s/he has understood the individuals' expression as the individual felt and use adequate non-verbal communication (nods, mirroring of emotions, etc.). When disaster survivors feel that they are listened to, they feel comforted and safe. Active listening helps in providing warmth and positive regard for the survivor.

- **Empathy:** Empathy is one of the basic and crucial psychosocial care techniques that help in building rapport and trust with the disaster survivors. Here, the caregiver understands the subjective experience of the survivor and communicates it to the survivor. E.g., 'I understand it must be very difficult for you to witness the pain and suffering', 'I can't imagine being in that situation', 'I know you have tried your best to support your family', etc. Expression of empathy can be practiced by these four basic elements; 1 Viewing from the other person's perspective, 2 Understanding their feelings and emotions, 3 Non-judgmental acceptance and 4 Communicating that the care provider has understood the other person's situation. Empathy also means experiencing the circumstances, feelings and emotions of the other person despite not having the real traumatic experience. It is difficult to experience from the other person's point of view

and it is an art which develops out of patient practice. Being empathetic towards the other person during the helping process will help in understanding the pain of the survivor and in initiating responsive psychosocial care activities for the survivor. Appropriate gender specific touch or gestures, adequate reassurances, mirroring of the other person's facial expressions/feelings and disclosure stories (when needed) aid in expressing empathy towards the disaster survivors.

- **Maintaining Routine:** Disaster breaks one's routine. Restarting one's daily activities is essential to bring functionality among disaster survivors. Daily routine might involve healthy eating habits, proper sleep, engagement in household chores, resuming occupation, taking usual medicines, physical activity, following family rituals and other social activities. Restarting routine would be difficult initially because of factors like loss, confusion and personal vulnerabilities. The caregiver has to motivate the survivors to start doing their activities of daily living and can help those who have significant difficulty in resuming earlier life. The caregiver should also monitor closely such individuals and provide opportunities to ventilate and express their difficulties.
- **Avoiding maladaptive patterns:** During disaster situations, availability of resources will be limited or become scarce, exceeding the individual's coping abilities. The negative consequences of disaster make people adapt negative coping strategies. Along with encouraging disaster survivors to practice adaptive coping strategies (active problem solving, talking or writing about the feelings, giving and taking help), the caregivers should also discourage maladaptive coping strategies. Some of the commonly used maladaptive patterns are; using drugs or psychoactive substances, over or under eating, fighting/beating/quarrelling, avoiding or escaping from thoughts/people/place, gambling etc. All the above psychosocial techniques help in speedy recovery of the survivors. Though all the techniques are important, the individuals can choose a particular or combination of techniques based on their need. Care to be taken to align these psychosocial techniques to the cultural and religious sentiments of the community.
- **Social Support:** Social support makes people feel safe and assured. Social Support can be classified into three orders: (1) Primary Social Support: Family, (2) Secondary Social Support: Friends, Neighbours, Colleagues, and (3) Tertiary Social Support: Government, Legal bodies, Non - Governmental Organisations, and Religious Institutions.

All these three sources of support are important as they safeguard when individuals face distress. Social support also enhances a person's well-being and coping. Disaster situations disturb, uproot or wipe out social support units, especially the primary and secondary support. For example, an individual can lose his/her family members or friends in the disaster. It is essential for caregivers to develop strategies to recreate social support units, create opportunities for survivors to gather in groups and encourage individuals in family rituals and community engagement activities.

- **Yoga and relaxation:** The unexpected confusion and uncertainty following any disaster, result in anxiety and fear. It would be difficult for individuals to relax because of the tremendous loss, continuous apprehension and fear of future. It is essential to train the survivors with anxiety or panic management strategies. Yoga and relaxation techniques can serve as such self-management strategies. Some of the yoga/relaxation techniques that can be practiced on a daily basis even in a restricted environment are given below: 36 Victorious Breathing (Ujjayi): This technique helps in calming the mind and body. The participants are asked to fill the lungs with air and breathe through nose making a snoring/hissing sound. Bellows Breathing (Bhastrika): It involves rapid inhalation and exhalation creating a yogic fire within oneself. The participants have to sit in a cross-legged position. Then they need to make a fist and place the folded arms near the shoulders. While the participant inhales, s/he has to raise the hands up and open the fists. Then exhale forcibly bringing the arms down and closing the fist. The process can be repeated for 20 rounds. Chanting: The participants are asked to create slow and progressive resonating vibration using the sounds aaa... uuu.... mmm.... Purifying Breathing (SudharshanaKriya): This is a cyclical breathing exercise in slow, medium and fast rates combining the victorious breathing, bellows breathing and chanting.
- **Mindfulness:** Imagining a peaceful and serene environment or natural ambience and focusing on breathing or looking at serene objects like illuminated candle, images of God, nature or meditating on religious texts with undivided attention. Jacobson's Progressive Muscular Relaxation (JPMR): It's progressively tightening and loosening muscles in the multiple parts of the body starting from head to toe. It is proved that stress gets accumulated in multiple parts of the body and manifested as pain. Systematic tightening and loosening of body muscles helps in

releasing suppressed emotions. The individual has to breathe in while tightening and gently release the tightening muscles while breathing out slowly.

- **Recreation:** Recreation helps in shifting one's focus from the negative emotions triggered by the disaster. People can be encouraged to participate in recreational activities like singing songs, dancing, playing and other culture specific activities. These recreational activities help in fast improvement of the normalization process. Recreation options can be made available in the community through folk lore, puppet shows and other cultural media. This also can be made use to provide disaster specific information and awareness. Humor can also be a part of recreation. Providing channels for people to laugh and cherish would drive faster recovery.
- **Spirituality:** Spirituality refers to the positive inner experiences that provide optimistic outlook towards life. It aims at establishing the connection between inner self of an individual and outer world. Spirituality also involves caring for self, others and the environment. It believes that there are things that are outside one's control and testing times offer platform for bettering oneself. It is a movement towards self-fulfillment. India, being a country of multiple faiths and religions, belief in God/nature/ offers support and peacefulness during difficult times. Questioning the supreme power is a part of the grieving process. This might get extended during the acceptance phase. The caregiver should not force anyone to perform specific spiritual rituals, but encourage survivors to practice their spiritual practices.
- **Externalization of interests:** Individual's roles get disturbed during disaster. Hence, positive rearrangement of roles based on the demands of the current situation is important. This ensures adjustment among the survivors. Shifting the focus to other constructive activities keeps the person engaged. It enhances the person's functionality as well. The caregiver should look for the interests and skills among the individuals or groups and encourage practicing the same on a daily basis. Activities constructed to remember the interests and skills of the individuals would make the survivors feel that their skills match with the need of the emerging situation. This would make them feel that they are not a burden for others, but a useful resource in community restoration.

## **10. Caring for carers: self-care strategies**

Emergency responders and healthcare workers managing radiation and nuclear emergencies face extraordinary challenges that create unique vulnerabilities requiring specialized attention. Unlike conventional disaster response, these professionals must navigate invisible radiation hazards, long-term health uncertainties, and complex technical protocols while experiencing both direct exposure risks and secondary traumatic stress from witnessing extensive human suffering. The compound nature of these stressors—including radiation-specific occupational stress, moral dilemmas between personal safety and professional duty, information overload, social isolation, and physical health impacts—creates overwhelming conditions that can compromise even the most resilient individuals. Extended work periods, fear of contamination affecting family members, and the psychological burden of making difficult decisions with limited information further amplify their susceptibility to stress-related complications.

Comprehensive self-care strategies are essential for maintaining responder effectiveness and well-being during radiation emergencies. These strategies encompass:

- Physical care through adequate sleep, nutrition, exercise, and proper protective equipment use;
- Psychological support including regular mental health check-ins, mindfulness techniques, and realistic expectation setting;
- Social connection through family communication and peer support networks;
- Professional development to build confidence and competency; and
- Boundary setting to prevent burnout.

Long-term resilience building requires ongoing health monitoring, participation in critical incident stress management programs, and development of personal protective factors through meaningful activities. Organizational support systems, including employee assistance programs, clear policies on exposure limits and rotation schedules, and access to mental health services, play crucial roles in creating sustainable frameworks for carer well-being. Ultimately, prioritizing carer self-care is both a moral imperative and practical necessity, as healthy responders provide better care to affected communities and ensure effective emergency response capacity over time.

## **11. Conclusion**

Many proposed mental health and psychosocial interventions do not require highly specialized skills or expensive equipment but demand multi-disciplinary approaches, cross-sector coordination, and systematic capacity building through staff training. Effective communication to affected populations and methods for disseminating radiation risk information enable public understanding and appropriate response. Early support during emergency situations helps prevent distress from evolving into severe mental health conditions, making early intervention a critical component of effective response strategies.

## Take Home Message:

- ❖ Psychosocial support: Helps reduce distress, promote coping, and restore a sense of safety and control.
- ❖ Core principles: Safety, calm, social connectedness, hope, self- and Community Efficacy and practical support.
- ❖ Mental health impact: Radiological emergencies cause fear, anxiety, stigma, uncertainty, and long-term stress.
- ❖ Survivor reactions: Normal reactions include shock and fear; abnormal reactions may include panic, PTSD, or prolonged anxiety.
- ❖ Vulnerable groups (children, elderly, pregnant women, people with disabilities, and those with pre-existing mental health conditions) in a community require special attention.
- ❖ Emotional and cognitive preparedness prior to the disaster helps to prepare for, and to cope with the stressors imposed by a disaster.
- ❖ Psychosocial first aid: Provide comfort, basic needs, clear information, and link people to services.
- ❖ Support techniques: Active listening, reassurance, problem-solving, and strengthening social support.
- ❖ A sound plans to mitigate the adverse impact of the disaster on the emotional, cognitive, and behavioral capacity of the individual.
- ❖ Being aware of burnout and using self- help techniques can help to reduce adverse outcomes.
- ❖ Caring for carers: Stress management, rest, peer support, and avoiding burnout.

## Activities:

### **Activity 1:**

- What are the common psychological reactions to radiation emergencies?
- What are the psychosocial care techniques for helping survivors?

### **Activity 2:**

- What are the warning signs of burnout among carers?
- How do you care for yourself as a carer during radiation emergencies?

### **Activity 3**

- Which of the following is considered as an abnormal reaction after a radiation emergency?
  - a. Outcry
  - b. Denial
  - c. Panic/exhaustion (correct answer)**
  - d. Intrusions
- Psychosocial first aid module developed by World Health organization includes the following strategies except;
  - a. Like (correct answer)**
  - b. Look
  - b. Listen
  - c. Link
- Which of the following is not a psychosocial care technique for helping disaster survivors?

a. Active listening

**b. Advice (correct answer)**

c. Empathy

d. Ventilation

**References:** (Adapted from)

- A framework for mental health and psychosocial support in radiological and nuclear emergencies. Geneva: World Health Organization; 2020. Licence: CC BY-NC-SA 3.0 IGO
- Indian Red Cross Society. (n.d.). *Psychosocial support in disasters (Module 5)*. <https://www.indianredcross.org/fmr/Module5.pdf>
- National Disaster Management Training Module-2, Psychosocial Care in Disasters. (<https://ndma.gov.in/sites/default/files/PDF/Technical%20Documents/NDMA-Module-2.pdf>)
- NEA (2024), Practical Guidance for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies, OECD Publishing, Paris ([https://www.oecd-nea.org/jcms/pl\\_97415/practical-guidance-for-mental-health-and-psychosocial-support-in-radiological-and-nuclear-emergencies?details=true](https://www.oecd-nea.org/jcms/pl_97415/practical-guidance-for-mental-health-and-psychosocial-support-in-radiological-and-nuclear-emergencies?details=true))
- Selye, H. (1950). Stress and the General Adaptation Syndrome. *British Medical Journal*, 1, 1383-1392. <https://doi.org/10.1136/bmj.1.4667.1383>

**Suggested Reading**

- NEA (2024), Practical Guidance for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies, OECD Publishing, Paris ([https://www.oecd-nea.org/jcms/pl\\_97415/practical-guidance-for-mental-health-and-psychosocial-support-in-radiological-and-nuclear-emergencies?details=true](https://www.oecd-nea.org/jcms/pl_97415/practical-guidance-for-mental-health-and-psychosocial-support-in-radiological-and-nuclear-emergencies?details=true))
- National Disaster Management Training Module-2, Psychosocial Care in Disasters. (<https://ndma.gov.in/sites/default/files/PDF/Technical%20Documents/NDMA-Module-2.pdf>)



## Chapter 24

### Risk Communication in Radiological and Nuclear Emergencies

#### Session Objectives:

Upon completion of the lesson the trainee would be able to:

- Define the concept and importance of risk communication in radiological and nuclear emergencies.
- Explain how human perception influence communication.
- Identify the key principles and strategies of effective risk communication.
- Describe how communication is integrated into national emergency response systems.
- Recognize challenges such as rumors, misinformation, and distrust.
- Appreciate the role of community engagement in ensuring compliance and trust.

#### 1. Introduction

Risk communication is a critical component of preparedness and response to radiological and nuclear emergencies. It involves timely, transparent, and accurate exchange of information between authorities, experts, media, and the public. The objective is not only to inform people about health risks but also to empower them to take protective actions and reduce fear, uncertainty, and misinformation.

#### 2. Human Perception and Risk

Human perception plays a central role in shaping responses during radiological or nuclear crises. Public actions are frequently influenced more by perceived threats than by actual scientific data. People interpret messages through the lens of their previous experiences, cultural background, and level of trust in institutions. As a result, the same message can be understood in vastly different ways across populations. When uncertainty prevails, and official communication is delayed or unclear, rumors and misinformation can spread quickly, amplifying anxiety and undermining public confidence. Understanding the audience—including their fears, beliefs, and

sources of information—is therefore critical for designing communication strategies that resonate and foster cooperation.

### 3. Key Principles of Risk Communication

Several foundational principles guide effective risk communication in radiological and nuclear emergencies.

- ❖ **Trust** – Trust is the cornerstone; without it, even scientifically accurate information may fail to influence behavior.
- ❖ **Timing** – Timing is equally crucial—authorities should share information early and regularly, even when complete details are not yet available, to prevent information vacuums that fuel speculation.
- ❖ **Empathy** – Communicators must demonstrate empathy by acknowledging public fears and validating concerns, thereby strengthening rapport with affected communities.
- ❖ **Transparency** – Transparency is essential in clarifying what is known, what remains uncertain, and what measures are being taken by authorities.
- ❖ **Consistency** – Consistency across agencies ensures that messages are aligned and do not confuse the public.
- ❖ **Listening & Feedback** – Equally important is listening, which includes surveillance and monitoring social media, hotlines, and community feedback to gauge and understand public concerns and tailor messages accordingly.
- ❖ **Addressing Rumors** – Finally, proactive rumor management helps correct false information swiftly before it spreads widely.

### 4. Strategies for Risk Communication

#### ❖ **Building Trust & Engaging with Communities**

Strengthening trust requires ongoing engagement with communities before, during, and after emergencies. Communication should be linked with accessible services, ensuring that the public sees tangible support associated with the messages they receive. Identifying trusted local influencers—such as community leaders, teachers, health workers, and religious figures—enhances message credibility. Using multiple communication channels ensures that critical

information reaches different demographic groups. Repeated dissemination of clear, actionable messages helps the public remember and follow recommended safety measures.

#### ❖ **Integrating Communication into Response Systems**

Effective risk communication is not an isolated activity but must be embedded within broader emergency management systems. Emergency plans should clearly define communication roles and responsibilities across stakeholders to ensure coherent and coordinated messaging. Adequate resources—including budgets, skilled workforce, and communication tools—must be allocated for this purpose. Training programs should regularly build the capacity of personnel involved in communication, particularly in interacting with media and addressing public concerns.

#### ❖ **Emergency Communication Practices**

Pre-established strategic communication plans allow authorities to respond quickly and consistently when an emergency arises. Proactive engagement with social media is essential, as it can serve both as a channel for public outreach and a source of real-time information on public concerns or misconceptions. Communication materials should be culturally appropriate and sensitive to the needs of different communities. Messages must be action-oriented, providing clear steps the public should take to stay safe, thereby reducing panic and enhancing compliance with protective measures.

### **5. Challenges in Risk Communication**

Risk communication during radiological and nuclear emergencies is fraught with challenges. The rapid spread of rumors, myths, and misinformation—especially through social media—can undermine response efforts. Political and economic sensitivities may influence communication strategies, sometimes restricting the openness with which information is shared. Multiple stakeholders, each with their own priorities, may create inconsistent messaging if coordination is weak. Scientific information during emergencies often evolves as new data emerges, making it difficult for authorities to provide definitive statements in the early stages. Additionally, intense media scrutiny and the public's existing distrust in institutions can make communication efforts more complex.

## 6. Role of Community Engagement

Community engagement is a core component of effective risk communication. Communities should be treated as partners rather than passive recipients of information. Involving them in planning, preparedness activities, and decision-making helps build ownership and resilience. Participatory tools such as hotlines, community surveys, focus group discussions, and public meetings support two-way communication and enable authorities to understand local concerns more deeply. Special attention must be given to vulnerable groups—including children, elderly individuals, persons with disabilities, and marginalized populations—who may require tailored messages and additional support to ensure their safety during radiological or nuclear emergencies.

### Take Home Message:

- ❖ Risk communication: Clear, timely information that reduces fear, supports decisions, and builds trust during radiological/nuclear emergencies.
- ❖ Risk Communication and Community Engagement (RCCE) is central to effective response to radiological and nuclear emergencies.
- ❖ Human perception: Emotions, beliefs, and trust strongly influence how people understand and act on messages.
- ❖ Effective communication principles: Be accurate, transparent, consistent, empathetic, and provide simple, actionable guidance.
- ❖ Proactive, transparent, empathetic, and consistent communication saves lives.
- ❖ Integration in response systems: Part of national emergency plans with designated spokespersons, coordinated messaging, and established communication protocols.
- ❖ Challenges: Poor communication can worsen crises and erode trust.
- ❖ Community engagement: Local participation improves acceptance, compliance, and sustained trust.

### Multiple Choice Questions (MCQs)

**Q1. The primary goal of risk communication in radiological emergencies is to:**

- a) Reduce radiation dose to responders
- b) Provide technical details of radiation physics
- c) Empower the public to take protective actions and reduce fear
- d) Avoid public involvement in decision-making

**Answer: c) Empower the public to take protective actions and reduce fear**

**Q2. Which of the following is considered the cornerstone of risk communication?**

- a) Timing
- b) Empathy
- c) Trust
- d) Transparency

**Answer: c) Trust**

**Q3. A person's response to risk is usually influenced more by:**

- a) Scientific data only
- b) Their perception and trust in authorities
- c) Government policies
- d) Media coverage alone

**Answer: b) Their perception and trust in authorities**

**Q4. In risk communication, the principle of “Transparency” means:**

- a) Withholding sensitive information until confirmed
- b) Sharing only positive outcomes
- c) Clarifying what is known, unknown, and being done
- d) Using complex scientific terms for accuracy

**Answer: c) Clarifying what is known, unknown, and being done**

**Q5. A common challenge in risk communication during radiological emergencies is:**

- a) Availability of medical teams
- b) Rumors, myths, and misinformation
- c) Radiation monitoring equipment failure
- d) Lack of hospital space

**Answer: b) Rumors, myths, and misinformation**

**Q6. Community engagement in risk communication helps by:**

- a) Reducing government expenditure
- b) Making communities passive receivers of information
- c) Building trust and improving compliance with protective actions
- d) Replacing emergency responders

**Answer: c) Building trust and improving compliance with protective actions**

**Q7. Which statement is MOST appropriate in risk communication?**

- a) “We cannot share information until all facts are known.”
- b) “Tell people what you know, what you don’t know, and what you are doing to find out.”
- c) “The public does not need to know technical details.”
- d) “Avoid addressing rumors to prevent drawing attention to them.”

**Answer: b) “Tell people what you know, what you don’t know, and what you are doing to find out.”**

### **Case Study & Role-Play Exercise: Risk Communication in a Radiological Emergency**

Through this exercise, participants practice:

- Delivering clear, transparent, and empathetic messages under pressure.
- Handling misinformation and rumors effectively.
- Coordinating messages between medical teams, authorities, and community leaders.
- Building public trust during high-stress emergencies.

### **Scenario**

At 09:00 hrs, a **Radiological Dispersal Device (RDD)** (dirty bomb) explodes in a busy market area of a metropolitan city. The explosion causes physical injuries and possible radioactive contamination of the surrounding environment.

Several injured and frightened people are rushing to nearby hospitals. Rumors are spreading rapidly on social media, including false claims that:

- “Radiation is spreading throughout the city.”

- “Thousands will die within hours.”
- “Hospitals are refusing to treat patients.”

Local television channels are demanding immediate statements from authorities.

### **Exercise Instructions**

**Divide trainees into groups** with assigned roles:

- Incident Commander / Health Authority Representative
- Public Information Officer (PIO)
- Medical Team Representative (ER doctor/nurse)
- Community Leader / Local Influencer
- Media Reporters (role-played by other participants)
- Concerned Public / Patients’ Relatives

### **Task 1: Press Briefing Simulation**

- The PIO and Incident Commander must prepare a **2-minute press briefing** that addresses:
  - What happened (facts known so far)
  - What is being done by authorities
  - Protective actions for the public
  - Rumors and misinformation

### **Task 2: Community Engagement Role-play**

- The Community Leader interacts with the public (role-played by participants) to reassure them.
- Address fears, explain protective steps (e.g., sheltering, avoiding contaminated areas, waiting for official guidance).

### **Task 3: Hospital ER Response Simulation**

- The Medical Team explains how they will handle self-evacuated patients arriving without triage.
- Communicate how contamination risks will be managed, while reassuring the public that care will not be denied.

### **Debrief Questions**

- How well did the “authority figures” balance transparency and reassurance?
- Did the press briefing address rumors and uncertainties?
- How effective was the community engagement approach in building trust?
- What improvements could be made in timing, language, or empathy?
- How did the medical team communicate both safety measures and compassion to walk-in patients?

### **References: (Adapted from)**

- IAEA (2019) Manual for First Responders to a Radiological Emergency. (<https://www.iaea.org/publications/7606/manual-for-first-responders-to-a-radiological-emergency>)
- IAEA (2012) Communication with the Public in a Nuclear or Radiological Emergency. EPR-Public Communications. (<https://www.iaea.org/publications/8889/communication-with-the-public-in-a-nuclear-or-radiological-emergency>)
- WHO (2016) Communicating Radiation Risks in Paediatric Imaging: Information to Support Healthcare Discussions about Benefit and Risk. (<https://www.who.int/publications/i/item/978924151034>)
- WHO (2020) Radiological and Nuclear Emergencies: Public Health Risk Communication and Community Engagement. (<https://iris.who.int/server/api/core/bitstreams/948a6854-c57d-4d03-8547-bc9d4c72a6c5/content>)

- AERB (2018) Safety Guide on Preparedness for Response to a Nuclear or Radiological Emergency (AERB/SG/NRE-1). (<https://www.aerb.gov.in/images/PDF/Criteria-for-Planning-Preparedness-and-Response-for-Nuclear-or-Radiological-Emergency.pdf>)
- BARC (2019) Radiation Emergency Medical Preparedness and Response Guidelines. ([https://www.barc.gov.in/barc\\_nl/2023/2023030411.pdf](https://www.barc.gov.in/barc_nl/2023/2023030411.pdf))
- Covello, V. & Sandman, P. (2001) Risk Communication: Evolution and Revolution. Harvard School of Public Health. (<https://www.orau.gov/hsc/ercwbt/content/ERCcdcenergy/content/activeinformation/resources/aCovelloSandmanarticle.pdf>)

### **Suggested Reading**

- IAEA (2012) Communication with the Public in a Nuclear or Radiological Emergency. EPR-Public Communications.
- WHO (2020) Radiological and Nuclear Emergencies: Public Health Risk Communication and Community Engagement.

## Pre-Training Test

### *(Medical Management of Radiological and Nuclear Emergencies)*

#### Part A – Multiple Choice Questions (MCQs)

**Q1.** Which principle of radiation protection ensures exposure is kept “As Low As Reasonably Achievable”?

- a) Justification
- b) Optimization
- c) ALARA
- d) Dose Limitation

**Answer:** c) ALARA

**Q2.** The unit of absorbed dose of radiation is:

- a) Sievert (Sv)
- b) Gray (Gy)
- c) Becquerel (Bq)
- d) Roentgen (R)

**Answer:** b) Gray (Gy)

**Q3.** Which of the following is **not** a source of occupational radiation exposure?

- a) Radiation therapy departments
- b) Industrial radiography units
- c) Food irradiation plants
- d) Fire stations

**Answer:** d) Fire stations

**Q4.** Acute Radiation Syndrome (ARS) primarily affects which organ system first?

- a) Cardiovascular
- b) Gastrointestinal
- c) Hematopoietic

d) Nervous system

**Answer:** c) Hematopoietic

**Q5.** The Radium Girls case study highlighted the dangers of:

a) Inhalation of uranium dust

b) External exposure to X-rays

c) Ingestion of radium paint during dial painting

d) Contamination from reactor accidents

**Answer:** c) Ingestion of radium paint during dial painting

### **Part B – True/False**

**Q6.** Radiation cannot cause long-term health effects like cancer.

**Answer:** False

**Q7.** PPE, time, distance, and shielding are the four key measures to reduce occupational exposure.

**Answer:** True

**Q8.** Industrial radiography accidents often occur due to improper source handling or equipment failure.

**Answer:** True

### **Part C – Short Answer Questions**

**Q9.** List two international agencies that provide guidelines on radiation safety.

**Answer:** IAEA (International Atomic Energy Agency), WHO (World Health Organization), ICRP (International Commission on Radiological Protection).

**Q10.** What is the first priority of medical management in a radiation emergency?

**Answer:** To save life by addressing life-threatening conventional injuries and stabilizing the patient before addressing radiation exposure/contamination.

## Post-Training Test

### (Medical Management of Radiological and Nuclear Emergencies)

#### Part A – Multiple Choice Questions (MCQs)

**Q1.** In a radiation emergency, the *first* priority in hospital triage is to:

- a) Decontaminate the patient immediately
- b) Manage life-threatening injuries
- c) Take dosimeter readings
- d) Collect patient history

**Answer:** b) Manage life-threatening injuries

**Q2.** A worker exposed to a stuck Ir-192 source in industrial radiography presents with erythema and blistering on the hand. This represents:

- a) Acute Radiation Syndrome – Hematopoietic subtype
- b) Cutaneous Radiation Syndrome
- c) Radiation Sickness – GI subtype
- d) Chronic Radiation Syndrome

**Answer:** b) Cutaneous Radiation Syndrome

**Q3.** Which countermeasure can reduce thyroid uptake of radioactive iodine?

- a) Calcium gluconate
- b) Potassium iodide (KI)
- c) Chelation therapy
- d) Sodium bicarbonate

**Answer:** b) Potassium iodide (KI)

**Q4.** According to ICRP, the annual occupational dose limit for radiation workers is:

- a) 50 mSv every year without averaging
- b) 20 mSv/year averaged over 5 years (no year >50 mSv)
- c) 100 mSv/year

d) No limit if PPE is used

**Answer:** b) 20 mSv/year averaged over 5 years (no year >50 mSv)

**Q5.** The Goiânia accident (1987) demonstrated the importance of:

- a) Radiotherapy in cancer treatment
- b) Emergency evacuation of nuclear plants
- c) Control and security of orphan sources
- d) Fractionation in radiation therapy

**Answer:** c) Control and security of orphan sources

### **Part B – True/False**

**Q6.** Patients who bypass triage and directly reach the emergency department should be promptly assessed for both life-threatening injuries and possible contamination.

**Answer:** True

**Q7.** Decontamination should be delayed until the radiation dose is measured and calculated.

**Answer:** False (life-saving measures and gross decontamination should not be delayed).

**Q8.** A Radiological Dispersal Device (RDD) is more likely to cause widespread panic and social disruption than immediate radiation deaths.

**Answer:** True

### **Part C – Short Answer / Scenario-Based**

**Q9.** Name two personal monitoring devices used to measure occupational exposure in radiation workers.

**Answer:** Thermoluminescent Dosimeter (TLD) badge, Electronic Dosimeter, Film Badge.

**Q10.** Scenario: A patient presents 2 hours after suspected exposure to a gamma source. Outline two immediate steps you would take in the emergency department.

**Answer:**

1. Stabilize ABCs (airway, breathing, circulation) and treat life-threatening injuries.
2. Perform contamination survey and begin decontamination if needed, while using PPE.

## Training Feedback Questionnaire

### **Part A – Participant Information (Optional)**

Name: \_\_\_\_\_

Institution/Organization: \_\_\_\_\_

Designation: \_\_\_\_\_

### **Part B – Training Content**

1. The training objectives were clearly defined.

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

2. The topics covered were relevant to my work.

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

3. The balance between theory and practical sessions was appropriate.

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

### **Part C – Training Delivery**

4. The trainers demonstrated good knowledge of the subject.

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

5. The training materials (presentations, handouts, case studies) were useful.

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

6. The interactive components (discussions, exercises, simulations) enhanced my learning.

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

### **Part D – Logistics and Organization**

7. The training was well organized and structured.

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

8. Training facilities, equipment, and support arrangements were satisfactory.

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

**Part E – Outcomes and Application**

9. I feel more confident in responding to radiological/nuclear emergencies after this training.

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

10. I will be able to apply the knowledge and skills gained in my workplace.

Strongly Agree  Agree  Neutral  Disagree  Strongly Disagree

**Part F – Open-Ended Questions**

11. What part of the training was most useful to you?

---

12. What aspects of the training could be improved?

---

13. Are there any additional topics you would like included in future trainings?

---

14. Any other comments or suggestions:

---

### List of Contributors

S. No.	Name
1.	Dr. Tej Prakash Sinha, Associate Professor Dept. of Emergency Medicine, Jai Prakash Narayan Apex Trauma Center (JPNATC), AIIMS, New Delhi
2.	Dr. Kaushal Kalra, Head of Dept., Medical Oncology, Safdarjung Hospital, New Delhi.
3.	Dr. Raju Karankale, SO/F, Bhabha Atomic Research Centre (BARC), Department of Atomic Energy (DAE), Mumbai, Maharashtra
4.	Dr. Bathula Sreekanth, SO/F, RSSD, Bhabha Atomic Research Centre (BARC), Department of Atomic Energy (DAE), Mumbai, Maharashtra
5.	Dr. Sanjeev Kumar Manikappa, Associate Professor, Dept. of Psychosocial Support in Disaster Management (DPSSDM), National Institute of Mental Health and Neuro Sciences-NIMHANS
6.	Dr. Ravindra S Jammihal, Former Senior Consultant, CBRN, Disaster Management Cell, MoHFW, GoI, Former Senior Occupational Health Physician, Bhabha Atomic Research Centre, Mumbai
7.	Dr. Malik Naseer Ahmed, CMO (SG), 8 <sup>th</sup> Bn, National Disaster Response Force (NDRF), New Delhi.
8.	Dr. Jyoti Purandare, Chief Medical Superintendent, Nuclear Power Corporation of India Limited NPCIL, Mumbai, Maharashtra.
9.	Dr. Jyoti, ADG (IH), APHO, Airport Health Organization, Directorate General of Health services, MoHFW, New Delhi.
10.	Dr. Sujata Arya, Dy. PHS (I), Airport Health Organization, Directorate General of Health services, MoHFW, New Delhi.
11.	Dr. Ghanishta Suri, Consultant for Disaster Mental Health and Psycho Social Support, add charge- Public Health and Nutrition
12.	Dr. Shuchi Bhagi, Scientist 'D', Institute of Nuclear Medicine & Allied Sciences (INMAS), New Delhi.
13.	Dr. Sudesh Pawar. Medical Officer/G and Certifying Surgeon, Kaiga Generating Station (KGS), Uttara Kannada District, Karnataka.
14.	Dr. Ganesan, Medical Officer /G and Certifying Surgeon, Tarapur Atomic Power Station (TAPS), Tarapur, Plaghar, Maharashtra
15.	Dr. Prabhakar Deo, Site Nodal Officer, Kudankulam Nuclear Power Project (KKNPP), Tirunelveli, Tamil Nadu.
16.	Dr Anita Ghose, MO/G and Certifying Surgeon, Kudankulam Nuclear Power Plant (KKNPP), Tirunelveli, Tamil Nadu.
17.	Dr. Sweta Agarwal, Medical Officer /F and Certifying Surgeon, Tarapur Atomic Power Station (TAPS), Tarapur, Plaghar, Maharashtra

18.	Dr. Prasad Agavane, Medical Officer /F and Certifying Surgeon, Kakrapar Atomic Power Station (KKPS), Kakrapar, Surat, Gujarat.
19.	Dr. Rajesh Bhaskar, Medical Officer /F and Certifying Surgeon, Narora Atomic Power Station (NAPS), Narora, Bulandshahar, Uttar Pradesh.
20.	Dr. J. R. Kennedy, Site Nodal Officer, Madras Atomic Power Station (MAPS), Kalpakkam, Tamil Nadu
21.	Dr. Pradeep Khasnobis, DDG, Disaster Management Cell, Ministry of Health and Family Welfare
22.	Dr. Yogesh, CMO (NFSG), Disaster Management Cell, Ministry of Health and Family Welfare
23.	Dr. Akanksha Khurana, SMO, Disaster Management Cell, Ministry of Health and Family Welfare
24.	Dr. Ajay Upadhyay, Consultant, Disaster Management Cell, Ministry of Health and Family Welfare
25.	Dr. Richa Chauhan, Consultant, Disaster Management Cell, Ministry of Health and Family Welfare

