Radiation Injuries

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Conflicts of Interest Disclosure

- No Conflicts of Interest to declare
- For health education

Examples of incidences

- July 1945: an atomic bomb in New Mexico
- August 1945: nuclear weapons detonated over Hiroshima and Nagasaki, nearly 200,000 acute deaths
- 1986: the Chernobyl nuclear reactor, series of explosions, 31 people died of ARS in the first few weeks after that event, unknown number of millions potentially suffered other long-term sequelae
- 1987: a radiosource was left at an abandoned radiotherapy institute in Goiania, Brazil, 112,000 requiring evaluation, 249 contaminations, 20 requiring hospital admissions, 4 deaths
- 2011: Fukushima Daiichi nuclear plant disaster, about 1000 disaster-related deaths, no deaths attributed to radiation injuries

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Table 2. *Cont.*

Poison, Victim of Poisoning (Time, Place and Died/Survived after Poisoning)	Case Description	Symptoms of Poisoning, Treatment Undertaken, Results of Autopsy
Isotope of polonium, Jasir Arafat (11 November 2004, Percy, France, died) [2]	[illegible]	[illegible]
Isotope of polonium, Aleksander Litwinienko (1 November 2006, London, UK, died) [2]	[illegible]	[illegible]
organophosphorus compound VX, Kim Jong-nam (13 February 2017, Kuala Lumpur, Malaysia, died) [2]	[illegible]	[illegible]

toxics MDPI

Review

Selected Political Criminal Poisonings in the Years 1978–2020: Detection and Treatment

Brunka et al, 2022

https://www.ft.com/content/53ecb19c-c01f-11e5-9fdb-87b8d15baec2

TECHNICAL NOTE

Lesson learned from Co-60 accident in Thailand

T. Thongpraparn, P. Chaudakshetrin and P. Buranapong

Department of Radiology, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand

Australasian Physical & Engineering Sciences in Medicine Volume 25 Number 4, 2002

- Co-60 radiation accident in Samutprakarn Province
- "Orphan sources" may end up in scrapyards
- An out-of-use Co-60 medical teletherapy source, left unattended in a disused parking area belonging to a Medical Dealer, was stolen and sold to a scrap dealer
- The Co-60 source was removed and left unshielded
- The unshielded source, estimated activity of 15.7 TBq (425 Ci)
- Some workers immediately became sick
- Eighteen days later when they went to a local hospital
- Ten victims developed radiation sickness symptoms, three died soon
- The accident is similar in some ways to the 1987 radiation accident at Goiania, Brazil, involving a Cs-137 radiotherapy source

Thongpraparn et al, 2002

- **Dirty bombs:** radiologic dispersal devices, combine radioactive materials with conventional explosives
- Panic and psychological distress

Radiation Physics

Nonionizing and Ionizing Radiation

- Radiation: energy emitted from a source
- The electromagnetic radiation spectrum
- **Nonionizing radiation:**
  - -long-wavelength, low-frequency, low-energy
  - -not carry enough energy to remove an electron from an atom, not produce charged ions when passing through
  - -UV rays, visible light rays, infrared rays, microwaves, radio waves
  - -Lasers, US, nuclear magnetic resonance systems in medical field
- **Ionizing radiation:** short-wavelength, high-frequency, high-energy

TABLE 128–1 Physical Properties of Radioisotopes

Isotope	Half-Life	Mode of Decay	Decay Energy (MeV)
Radioisotopes of Medicine and Research			
^{3}H	Stable		
^{131}I	8 days	β^-	0.97
^{201}Tl	73 hours	EC	0.41
^{99m}Tc	6 hours	IT	0.14
^{133}Xe	5.27 days	β^-	0.43
^{67}Ga	78 hours	EC	1.00
^{137}Cs	30.17 years	β^-	1.17
^{18}F	109 months	β^-, EC	1.65
Military Radioisotopes			
^{3}H	12.26 years	β^-	0.02
^{90}Sr	28.79 years	β^-	0.55
^{233}U	7.1×10^5 years	α, SF	4.68
^{238}U	4.51×10^9 years	α, SF	4.27
^{210}Po	138 days	α	5.307
^{239}Pu	24,400 years	α, SF	5.24
^{241}Am	470 years	α, γ	5.14/0.02

EC = electron capture; IT = isomeric transition from upper to lower isomeric state; MeV = megaelectron volts; SF = spontaneous fission.

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Irradiation, Contamination, Incorporation

- Contamination: radioactive substance covers an object completely or in part
- Incorporation: radionuclide is taken up by tissue via some route that permits radionuclide to enter the body

Table 30-5: Radiation Exposure vs. Contamination

Incident	Radiation Location	Source Type	Physical State	Patient Decontamination Necessary	Secondarily Contaminating
Exposure without skin contact (Irradiation)	External	Electro-magnetic radiation (energy waves)	None	No	No
External Contamination	External (skin surface)	Particles (matter)	Solid Liquid	Yes Yes	Yes Yes
Internal Contamination	Internal	Particles (matter)	Solid Liquid Gas	Yes Yes No	Yes Yes No

Table 30-6: Equivalent Chemical vs. Radiological Contamination Terminology

Chemical	Radiological
Absorption	Internal contamination
Distribution	Incorporation
Metabolism (catabolism)	Incorporation
Elimination	Decorporation

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Types of radiation

TABLE 10-1 Types of Radiation

Type (Symbol)	Charge	Penetration	Shield	Hazard	Source
Alpha	+2	Few centimeters in air	Paper, keratin layer of skin	Internal contamination only; requires special detection devices	Heavy radioisotopes (e.g., plutonium, uranium, radon)
Beta	−1	~8 mm into skin	Clothing	External (skin) and internal contamination	Most radioisotopes decay by beta followed by gamma emission
Positron	+1	~8 mm into skin	Lead, steel, or concrete	Interacts with electrons and releases photons of energy	Medical tracers
Neutron	0	Variable	Material with high hydrogen content	Whole-body irradiation	Nuclear power plants, particle accelerators, weapons assembly plants
Gamma and radiograph	0	Several centimeters in tissue	Concrete, lead	Whole-body irradiation	Most radioisotopes decay by beta followed by gamma emission

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Table 30-2: Radiation Summary and Shielding

Name	Type	Mass (u)	Charge	Penetration Distance	Main Problem	Adequate Shielding
Alpha	Particle	4	+2	1 to 3 inches (2.54 to 7.62 cm) through air Cannot penetrate dead outer layer of skin (stratum corneum)	Contamination	A single sheet of paper Standard precautions PPE
Beta	Particle	1/1,823	-1 (electron) or +1 (positron)	10 to 12 feet (3 to 3.7 m) through air Can penetrate dead outer layer of skin (stratum corneum), a few millimeters (mm) into the skin	Contamination	Aluminum foil Thick plastic
Neutron	Particle	1	0	Meters (m) through air Several cm into or through the body	Exposure (Irradiation) or Neutron (n) capture: $^{23}Na + n \rightarrow {}^{24}Na$	Water, polystyrene, paraffin wax, wet concrete, or other materials with high hydrogen content
X-ray	Electro-magnetic radiation (energy waves)	0	0	300 feet (91 m) through air Through the body	Exposure (Irradiation)	Lead Concrete
Gamma	Electro-magnetic radiation (energy waves)	0	0	0.5 mile (0.8 km) through air Through the body	Exposure (Irradiation)	Thick lead (several feet) Thick concrete (several feet) Depleted uranium

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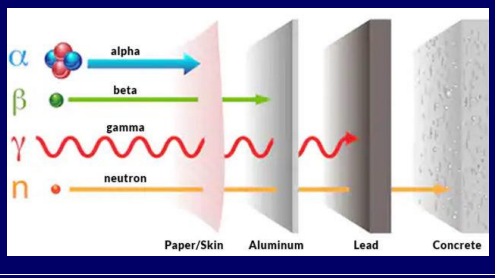

https://marshield.com/choosing-the-right-radiation-shielding-factors-considered-by-a-shielding-materials-expert/

Half-Life (HL)

- **Physical Half-Life**
  Time (in minutes, hours, days, or years) required for the activity of a radioactive material to decrease by one half due to radioactive decay
- **Biological Half-Life**
  Time required for the body to eliminate half of the radioactive material
- **Effective Half-Life**
  The net effect of the combination of the physical and biological half-lives in removing the radioactive material from the body

Biologic Effect of Ionizing Radiation

- Cellular effects
- High doses: causes cell death
- Lower doses: interrupt cellular reproduction through inhibition of mitosis, resulting in cellular injury with delayed onset of effects
- Rapidly dividing cells with short life spans: cells most vulnerable, because they are quickly depleted, new cells are unable to replete

Measuring radiation

TABLE 10-2 Radiation Units of Measure

Description	Conventional Units	SI Unit	Conversion
Activity	Curie	Becquerel	1 Bq = ~2.7 × 10^{-11} Ci
Units of activity describe the amount of radioactivity present.			1 Ci = ~3.7 × 10^{10} Bq
Exposure	Roentgen	Coulomb per kilogram	1 R = 2.58 × 10^{-4} C^2/kg
Units of exposure measure the amount of radiographs or gamma radiation that produces a given number of ionizations in air.			
Absorbed dose	rad	Gray	1 rad = 0.01 Gy
Units of absorbed dose can be applied to any type of radiation and reflect the energy imparted to matter.			1 Gy = 100 rad
Dose equivalent	Roentgen equivalents man	Sievert	1 rem = 0.01 Sv
Units that provide a common scale of measure for the different types of radiation.			1 Sv = 100 rem

Abbreviation: SI = International System of Units.

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Monitoring equipment

TABLE 10-3 Radiation Monitoring Equipment

Equipment Type	Device	Common Type of Measurement	Units Commonly Recorded
Dosimeter	Thermoluminescent dosimeter or film badge	Cumulative dose of beta, radiograph, and gamma	Roentgen equivalents man or sieverts
Dosimeter	Pocket dosimeter	Cumulative exposure to radiogrpah and gamma	Milliroentgen
Survey meter	Geiger-Müller tube	Low exposure rates of radiograph, gamma, and beta[a]	Counts per minute[b]
Survey meter	Ion chamber	Higher exposure rates of radiograph and gamma	Milliroentgen per hour

[a]With special instrument probes, alpha radiation can also be detected.
[b]2500 counts per minute equal approximately 1 mR/h.

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TABLE 128–2 Annual Estimated Average Effective Dose Equivalent in the United States

Source	Dose[a] mSv/year	mrem/year	% of Total dose
Natural			
Cosmic	0.27	27	5
Internal	0.31	31	5
Radon[b]	2.29	233	37
Terrestrial	0.19	19	3
Subtotal	3.10	310	50
Human-Made			
Consumer products	0.12	12.4	2
Nuclear medicine	0.74	74.4	12
Occupational	<0.01	0.62	0.1
Medical procedures	2.23	223.2	36
Subtotal	3.10	310	50
Total	6.20	620	100

[a]All doses are averages and contain some variability within the measurement.
[b]Average effective dose to bronchial epithelium.
mSv = millisieverts; mrem = millirem.
Data from Mettler FA, Bhargavan M, Faulkner K, et al. Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources—1950-2007. *Radiology*. 2009 Nov;253(2):520-531.

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Allowed Annual Dose of Radiation

TABLE 10-4 Selected Approximate Levels of Radiation Exposure

Natural background radiation	620 mrem/y (U.S. average)
Chest radiograph (effective dose)	10 mrem
Abdominal radiograph	120 mrem
Lumbar spine radiograph	70 mrem
CT head	200 mrem
CT chest	700 mrem
CT abdomen or pelvis	1000 mrem
Jet travel	1 mrem per 1000 miles traveled
Annual radiation dose limit (public)	100 mrem/y[a]
Occupational exposure limit	5000 mrem/y
Lethal dose in 50% of exposed subjects within 60 d (3.5–4.5 Gy)	350,000–450,000 mrem (350–450 rad[b])

[a]Over natural background radiation.
[b]1 rem (dose equivalent) = 1 rad (absorbed dose or exposure).

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Pathophysiology

Direct effects:

- particles physically damage the DNA in a cell, can occur at the sugar phosphate backbone, hydrogen bonds, or base molecules
- High-LET radiation: more likely to cause direct effects
- Mutation, may then result in alteration of germ line, development of a neoplasm, or cell death.

Pathophysiology

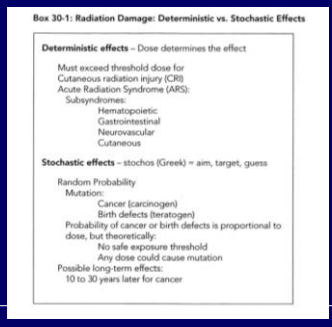
Indirect effects:

- when radiation impacts a molecule and creates a reactive species, then chemically reacts with organic molecules in cells altering their structure or function
- Predominantly caused by low-LET radiation (x-rays, gamma-rays, fast electrons)

Pathophysiology

- Bystander effect: refers to cellular damage in unirradiated cells that neighbor irradiated cells.
- Genomic instability: a single mutation followed by a cascade of further mutations altering the fidelity of genomic replication

Stochastic effect/ deterministic effects



Box 30-1: Radiation Damage: Deterministic vs. Stochastic Effects

Deterministic effects – Dose determines the effect

Must exceed threshold dose for
Cutaneous radiation injury (CRI)
Acute Radiation Syndrome (ARS):
Subsyndromes:
Hematopoietic
Gastrointestinal
Neurovascular
Cutaneous

Stochastic effects – stochos (Greek) = aim, target, guess

Random Probability
Mutation:
Cancer (carcinogen)
Birth defects (teratogen)
Probability of cancer or birth defects is proportional to dose, but theoretically:
No safe exposure threshold
Any dose could cause mutation
Possible long-term effects:
10 to 30 years later for cancer

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Lethal Dose of Radiation

- The $LD_{50/60}$: the dose of penetrating ionizing radiation that will result in the deaths (lethal dose) of 50% of the exposed population within 60 days without medical treatment
- The most commonly cited human value: LD50/60 of approximately 3.5 to 4.5 Gy (350 to 450 rad)

Clinical Effects of Radiation

Local Radiation Injury/ Cutaneous radiation injury

- Partial body exposure, rarely causes systemic manifestations
- Dose dependent cutaneous involvement
- the 1st week: asymptomatic or may be transient erythemaa (6 Gy), hyperesthesia, itching
- the 2nd week: erythema progresses to hair loss (3 Gy)
- The 3rd week: skin tenderness, swelling, pruritus
- the 4th week: dry (10 to 15 Gy) or wet (20 to 50 Gy) desquamation and radionecrosis with ulceration (>50 Gy)

Local Radiation Injury/ Cutaneous radiation injury

- May be indistinguishable from thermal burns, except for delayed onset of prolonged and severe pain
- At doses > 50 Gy, onset of pain will occur immediately, indistinguishable from thermal burns
- Surgical intervention: may be required

Table 1: Grades of Cutaneous Radiation Injury

GRADE	SKIN DOSE	PRODROMAL STAGE	LATENT STAGE	MANIFEST ILLNESS STAGE	THIRD WAVE OF ERYTHEMAS	RECOVERY	LATE EFFECTS
I	>2 Gy (200 rads)6	1-2 days postexposure or not seen	no injury evident for 2-5 weeks postexposure7	•3-5 weeks postexposure, lasting 20-30 days: redness of skin, slight edema, possible increased pigmentation •6-7 weeks postexposure, dry desquamation	not seen	complete healing expected 28-40 days after dry desquamation (3-6 months postexposure)	•possible slight skin atrophy •possible skin cancer decades after exposure
II	>15 Gy (1500 rads)	6-24 hours postexposure with immediate sensation of heat lasting 1-2 days	no injury evident for 1-3 weeks postexposure	•1-3 weeks postexposure: redness of skin, sense of heat, edema, skin may turn brown •5-6 weeks postexposure, edema of subcutaneous tissues and blisters with moist desquamation •possible epithelialization later	10-16 weeks postexposure, injury of blood vessels, edema, and increasing pain epilation may subside, but new ulcers and necrotic changes are possible	healing depends on size of injury and the possibility of more cycles of erythema	•possible skin atrophy or ulcer recurrence •possible telangiectasia (up to 10 years postexposure) •possible skin cancer decades after exposure
III	>40 Gy (4000 rads)	4-24 hours postexposure, with immediate pain or tingling lasting 1-2 days	none or less than 2 weeks	•1-2 weeks postexposure: redness of skin, blisters, sense of heat, slight edema, possible increased pigmentation followed by erosions and ulceration as well as severe pain	10-16 weeks postexposure: injury of blood vessels, edema, new ulcers, and increasing pain possible necrosis	can involve ulcers that are extremely difficult to treat and that can require months to years to heal fully	•possible skin atrophy, depigmentation, constant ulcer recurrence, or deformity •possible occlusion of small vessels with subsequent disturbances in the blood supply, destruction of the lymphatic network, regional lymphostasis, and increasing fibrosis and sclerosis of the connective tissue •possible telangiectasia •possible skin cancer decades after exposure
IV	>550 Gy (55,000 rads)	occurs minutes to hours postexposure, with immediate pain or tingling, accompanied by swelling	none	•1-4 days postexposure accompanied by blisters •early ischemia (tissue turns white, then dark blue or black with substantial pain) in most severe cases •tissue becomes necrotic within 2 weeks following exposure, accompanied by substantial pain	does not occur due to necrosis of skin in the affected area	recovery possible following amputation of severely affected areas and possible skin grafts	•continued plastic surgery may be required over several years •possible skin cancer decades after exposure

5 Especially with beta exposure
6 The Gray (Gy) is a unit of absorbed dose and reflects an amount of energy deposited in a mass of tissue (1 Gy = 100 rads).
7 Skin of the face, chest, and neck will have a shorter latent phase than the skin of the palms of the hands and the soles of the feet.

https://www.cdc.gov/nceh/radiation/emergencies/pdf/cri.pdf

Acute Radiation Syndrome

- After a significant exposure (whole-body gamma dose exceeds 2 Gy) within a 24-hour time period
- Can also occur in the setting of neutron source exposure or internal contamination with alpha and/or beta radiation
- 4 distinct phases: prodrome, latent phase, manifest-illness, recovery

The prodromal phase

- Transient autonomic nervous system
- Nausea, vomiting, anorexia, diarrhea accompanied by hypotension, pyrexia, diaphoresis, cephalgia, and fatigue
- Directly related to the dose received: high doses cause acute and severe symptoms, lower doses lead to milder symptoms and prolonged onset

Table 30-7: Prodromal Phase: Severity of Signs and Symptoms Based on Absorbed Dose of Radiation

Signs and Symptoms	1 to 2 Gy	2 to 4 Gy	4 to 6 Gy	>8 Gy
Vomiting Onset Incidence (%)	>2 h 10 to 50	1 to 2 h 70 to 90	<1 h 100	<10 min 100
Diarrhea Onset Incidence (%)	None —— ——	None to mild —— ——	Mild to moderate 3 to 8 h <10	Heavy <1 h ~100
Temperature Onset Incidence (%)	Normal —— ——	<38.5°C 1 to 3 h 10 to 80	Fever >38.5°C 1 to 2 h 80 to 100	High fever >38.5°C <1 h 100
Headache Onset Incidence (%)	Slight —— ——	Mild —— ——	Moderate 4 to 24 h 50	Severe 1 to 2 h 80 to 90
Level of Consciousness Onset Incidence (%)	Normal —— ——	Normal —— ——	Normal —— ——	Unconscious for sec to min 100% with >50 Gy

Source: Radiation Emergency Medical Management (REMM): http://www.remm.nlm.gov/ars_timephases1.htm, http://www.remm.nlm.gov/ars_timephases2.htm, http://www.remm.nlm.gov/ars_timephases3.htm, and http://www.remm.nlm.gov/ars_timephases5.htm.

Table 30-8: Prodromal Phase Key Manifestations Predict Survival Prognosis for ARS

Prognosis	Whole-Body Radiation Dose	Prodromal Phase Key Manifestations
Survival likely (probable)	<2 Gy	No signs or symptoms, or mild nausea and vomiting (N/V) for a few hours
Survival possible	2 to 8 Gy	Early, persistent N/V for 24 to 48 h
Survival unlikely (improbable)	>8 Gy	Early, severe, persistent N/V, diarrhea, and shock. Loss of consciousness signals poor prognosis. Coma heralds death. Death often within ≤72 h.

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The latent phase

- A symptom-free interval the
- Depend on the received dose, with larger doses resulting in a shorter duration
- Doses < 4 Gy: associated with a period that may last 1-3 weeks

The manifest illness phase

- Subdivided into 3 dose-dependent syndromes hallmarked by the affected organ system

TABLE 10-5 Acute Radiation Syndrome

Approximate Dose	Onset of Prodrome	Duration of Latent Phase	Manifest Illness
>2 Gy (200 rad)	Within 2 d	1–3 wk	Hematopoietic syndrome with pancytopenia, infection, and hemorrhage; survival possible
>6 Gy (600 rad)	Within hours	<1 wk	GI syndrome with dehydration, electrolyte abnormalities, GI bleeding, and fulminant enterocolitis; death likely
>20–30 Gy (2000–3000 rad)	Within minutes	None	Cardiovascular/CNS syndrome with refractory hypotension and circulatory collapse; fatal within 24–72 h

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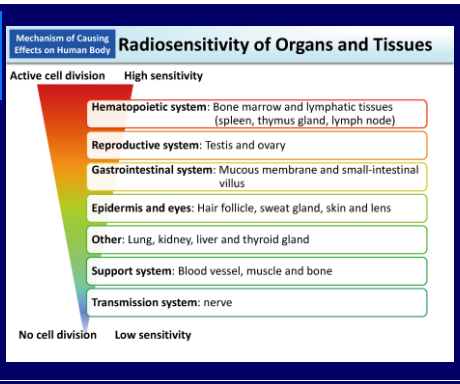

https://www.env.go.jp/en/chemi/rhm/basic-info/1st/03-02-06.html

Hematopoietic Syndrome

- With doses > 2 Gy
- The first affected organ system
- Damage the bone marrow stem cells, destruction of the circulating hematopoietic cells
- Lymphocytes: preferentially destroyed
- The peripheral lymphocyte count: the most readily available marker to grade the extent of the injury
- Granulocytes and platelets: markers of inflammation, their counts initially rise following exposure, but reach a nadir within 30 days of the injury
- Morbidity and mortality: pancytopenia, immunosuppression, hemorrhage

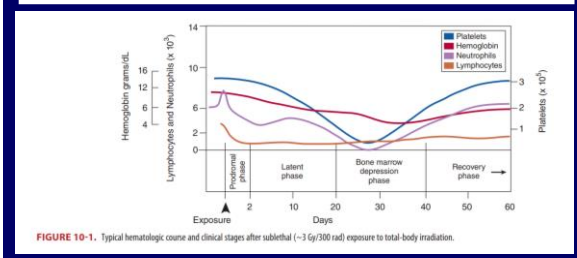

FIGURE 10-1. Typical hematologic course and clinical stages after sublethal (~3 Gy/300 rad) exposure to total-body irradiation.

The lymphocyte nadir: typically occurs 8-30 days postexposure

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GI Syndrome

- Doses > 6 Gy (>600 rad)
- Nausea, vomiting, and diarrhea within hours of exposure
- A short latent phase lasting up to 1 week follows
- A recrudescence of severe nausea, vomiting, diarrhea, and abdominal pain: indicates the phase that occurs after the failure to replenish the lost intestinal mucosa.
- Massive fluid and electrolyte shifts, translocation of enteric flora into the bloodstream, leading to the development of fulminant enterocolitis

Neurovascular Syndrome

(Cardiovascular and Central Nervous System)

- Doses > 12 Gy
- Mechanism: combination of radiation-induced vascular lesions & free radical induced neuronal death, cerebral edema
- Immediate persistent and intractable hypotension, prostration, nausea, vomiting, explosive bloody diarrhea
- CNS symptoms: develop within hours, seizures, lethargy, disorientation, ataxia, tremors
- Hyperthermia, loss of motor control, apathy, cardiovascular shock
- The lymphocyte count quickly falls to near-zero levels
- Death from circulatory collapse: within 24-48 hours

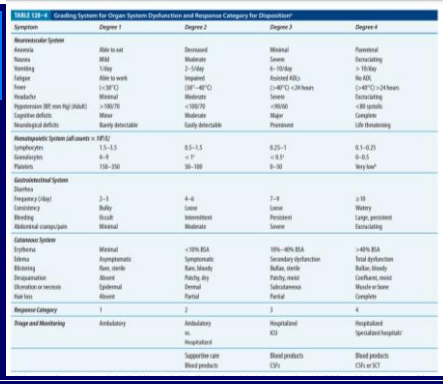

TABLE 126–4 Grading System for Organ System Dysfunction and Response Category for Disposition[a]

Symptom	Degree 1	Degree 2	Degree 3	Degree 4
Neurovascular System				
Anorexia	Able to eat	Decreased	Minimal	Parenteral
Nausea	Mild	Moderate	Severe	Excruciating
Vomiting	1/day	2–5/day	6–10/day	> 10/day
Fatigue	Able to work	Impaired	Assisted ADLs	No ADL
Fever	(<38°C)	(38°–40°C)	(>40°C) <24 hours	(>40°C) >24 hours
Headache	Minimal	Moderate	Severe	Excruciating
Hypotension (BP, mm Hg) (Adult)	>100/70	<100/70	<90/60	<80 systolic
Cognitive deficits	Minor	Moderate	Major	Complete
Neurological deficits	Barely detectable	Easily detectable	Prominent	Life threatening
Hematopoietic System (all counts × 10^9/L)				
Lymphocytes	1.5–3.5	0.5–1.5	0.25–1	0.1–0.25
Granulocytes	4–8	< 1[b]	< 0.5[b]	0–0.5
Platelets	150–350	50–100	0–50	Very low[b]
Gastrointestinal System				
Diarrhea				
Frequency (/day)	2–3	4–6	7–9	≥ 10
Consistency	Bulky	Loose	Loose	Watery
Bleeding	Occult	Intermittent	Persistent	Large, persistent
Abdominal cramps/pain	Minimal	Moderate	Severe	Excruciating
Cutaneous System				
Erythema	Minimal	< 10% BSA	10%–40% BSA	>40% BSA
Edema	Asymptomatic	Symptomatic	Secondary dysfunction	Total dysfunction
Blistering	Rare, sterile	Rare, bloody	Bullae, sterile	Bullae, bloody
Desquamation	Absent	Patchy, dry	Patchy, moist	Confluent, moist
Ulceration or necrosis	Epidermal	Dermal	Subcutaneous	Muscle or bone
Hair loss	Absent	Partial	Partial	Complete
Response Category	1	2	3	4
Triage and Monitoring	Ambulatory	Ambulatory vs. Hospitalized	Hospitalized ICU	Hospitalized Specialized hospitals[c]
		Supportive care Blood products	Blood products CSFs	Blood products CSFs or SCT

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Table 30-9: Latent Phase Duration Based on Absorbed Dose of Radiation

Signs and Symptoms	1 to 2 Gy	2 to 4 Gy	4 to 6 Gy	>8 Gy
Latent Phase Duration (days)	21 to 35	18 to 28	8 to 18	0

Source: Radiation Emergency Medical Management (REMM): http://www.remm.nlm.gov/ars_timephases1.htm, http://www.remm.nlm.gov/ars_timephases2.htm, http://www.remm.nlm.gov/ars_timephases3.htm, and http://www.remm.nlm.gov/ars_timephases5.htm.

Table 30-10: Manifest Illness (Critical) Phase: Severity of Signs and Symptoms Based on Absorbed Dose of Radiation

Signs and Symptoms	1 to 2 Gy	2 to 4 Gy	4 to 6 Gy	>8 Gy
Onset (days)	>30	18 to 28	8 to 18	0 (Immediate)
Fatigue or weakness	Yes	Yes	Yes	Yes
Epilation (hair loss)	None	Moderate	Moderate to complete	Complete
Onset	--------	≥15 days	11 to 21 days	≤10 days
Infections	No	**Yes**	**Yes**	**Yes**
Bleeding	No	**Yes**	**Yes**	**Yes**
Shock	No	No	No	Yes
Coma	No	No	No	Yes
Lethality (%)	0	0 to 50	20 to 70	~100 by 1 to 2 weeks
Onset (weeks)	N/A	6 to 8	4 to 8	1 day

Source: Radiation Emergency Medical Management (REMM): http://www.remm.nlm.gov/ars_timephases1.htm, http://www.remm.nlm.gov/ars_timephases2.htm, http://www.remm.nlm.gov/ars_timephases3.htm, and http://www.remm.nlm.gov/ars_timephases5.htm.

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Emergency response planning

- Multiple community-wide organizations: hospitals, EDs, and public safety, public health, emergency management officials
- Every EMS system: prehospital plan for the evacuation of victims from a radiation disaster
- Every hospital: protocol detailing instructions for receiving and treating radiation victims

Radiation Protection

- Time
- Distance
- Shielding
- Quantity

Prehospital Emergency Medical Management

- Emergency responders should rapidly establish incident command in a situation involving radioactive materials
- Care and transportation of seriously injured victims should not be delayed, even if the patient is contaminated

ED Notification/Preparation

- First responders must communicate with hospitals prior to arrival e.g. circumstances of the event, number of victims, traumatic injuries, type of radiologic insult
- Local radiation specialists, health physics professionals
- If radiation monitors are not available, patients should undergo decontamination and then be surveyed for residual contamination when monitoring equipment is available

TABLE 10-6 ED Preparation

Initiate hospital disaster plan

- Mobilize hospital radiation experts (radiation safety officer, nuclear medicine and radiation oncology experts and staff).
- Request dosimeters for staff and radiation monitoring and survey instruments.

Prepare the ED

- Establish an ad hoc triage area based on the location designated in the hospital disaster plan.
- Establish a "contaminated" area and "clean" area separated by a buffer zone using ropes, tape, and signs to designate areas.
- Remove contaminated outer garments when leaving contaminated area and have your body surveyed with a radiation meter prior to leaving the area.
- Cover floors with plastic or paper secured with heavy tape.
- Remove pregnant women, nonessential personnel, and nonessential equipment.
- Request extra gloves, other medical supplies, and extra large plastic bags for disposal.

Use standard precautions to protect staff

- Staff should wear a water-resistant gown, cap, and shoe covers to keep contaminants off skin and clothes.
- Double-glove with inner glove taped in place, changing the top pair after handling contaminated items and between patients.
- N95 masks, if available, are recommended, but surgical masks should be adequate.
- Survey hands and clothing at frequent intervals with a radiation meter.
- Dosimeters, if available, should be worn at the collar, under protective clothing.

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Triage

- Field triage protocols: minor, delayed, immediate, or deceased depending on physical trauma or burns
- Not alter triage principles based solely on radiation exposure
- Radioactive contamination: never immediately life-threatening, do not delay treatment of life-threatening injuries for radiologic surveying
- Morbidity and mortality: physical trauma, thermal burns, significant medical conditions

Triage

- First responders: must use universal precautions, should assume that all victims are contaminated
- Most events will only require C- or D-level protection

Treatment

- Most radiation injuries: not immediately life-threatening, there is usually time to determine whether patient was irradiated, externally contaminated, or internally contaminated
- Early treatment decisions: based on biologic dosimetry, signs and symptoms evident in the first 24 to 48 hours, laboratory test results

Decontamination of external contamination

- Goal: to decrease total exposure of patient and staff, by minimizing radiation exposure from a source external to the body to a level that is as low as reasonably achievable

TABLE 10-7 Steps of Patient Decontamination

Assess external contamination

- Contact radiation safety officer.
- Assess contamination with radiation survey meter (Geiger counter).
- Evaluate for radioactive shrapnel. Easily accessible pieces should be removed with a forceps and placed in a lead container.
- Document contamination pattern on a body diagram.
- Swab each nostril separately to estimate level of internal contamination of the lungs.

Decontaminate whole body

- Carefully cut and roll clothing away from the face to contain contamination.
- Double bag clothing and label as hazardous waste.
- Wash wounds first with saline or water.
- If facial contamination is present, rinse as appropriate.
- Gently cleanse intact skin and avoid scrubbing.
- Repeat patient scan with radiation survey meter. Repeat washing until radiation is <2 times background. Avoid scrubbing.
- Cover wounds with waterproof dressing.

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Box 30-6: Radiation Treatment: Decontamination

Respiratory

Ensure adequate ventilation and oxygenation

Skin decontamination is not necessary for

Exposure

Irradiation by rays (energy) from an external source emitting x-rays or gamma rays

Victims are not radioactive and do not pose danger to rescuers, emergency responders, hospital staff

Radioactive gas exposure (e.g., radon, xenon-133)

Skin and hair decontamination is necessary for

External contamination from skin contact with radioactive solids, liquids, or aerosols

Remove clothing, jewelry, watches, shoes, hair pieces & wigs, etc.

Wash with tepid (body temperature) water and soap or a mild liquid detergent (where water is available)

Pay close attention to skin folds

Gently dab skin (where water is not available)

Avoid vigorous scrubbing or abrading the skin

At a minimum, dispense (then collect and properly discard) baby wipes to remove gross contamination from hands and face

Skin decontamination goals:

Environmental background radiation levels whenever possible

Twice background radiation levels or greater may be acceptable in scarce resource situations

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Treatment of Local radiation injury

- Focuses on analgesia, wound care, infection control
- Interruption of radiation-induced inflammation in the dermis
- Burn care
- Consider applying topical steroids to control local inflammation, vitamin A, C, E, pentoxifylline to decrease blood viscosity & increase blood flow

Treatment of Local radiation injury

- Silver-based creams
- Hyperbaric oxygen may be considered
- Systemic steroids: not recommended

Treatment of Acute radiation syndrome

- Immediate treatment of the irradiated patient: alleviating symptoms of the prodromal phase
- Pain: acetaminophen and opioids
- if dose > 5 to 6 Gy, avoid using NSAIDs, may be at risk for GI bleeding
- Antiemetics: Ondansetron or other 5-hydroxytryptamine-3 antagonists
- Antidiarrheal agents: use of fluoroquinolone for 2 -4 days after an acute exposure

Treatment of Acute radiation syndrome

Biologic dosimetry:

- Use of physiological, chemical, biological markers to reconstruct doses & assess probability of developing ARS
- Cytogenetic analysis for chromosomal aberrations (dicentrics): the gold standard
- Time of onset of all symptoms, especially vomiting & diarrhea, laboratory analyses (e.g., rate & nadir of lymphocyte depletion), clinical signs

Treatment of Acute radiation syndrome

- Obtain baseline CBC and check every 6 hours for 24-48 hours
- Obtain baseline serum amylase, because dose-dependent increases are expected after 24 hours in a significant exposure
- Consultation with hematologist/ oncologist/infectious disease specialist

Treatment of Acute radiation syndrome

- Mainly on the support and recovery of the hematologic system
- May require prophylactic antibiotics, antifungals, antivirals or appropriate monotherapy for infections

Treatment of Internal contamination

- Generally does not produce early symptoms
- Consider if persistently high radiation survey readings noted, all nose or mouth contamination cases
- Obtain 24-hour urine collection for possible radionuclide identification
- Consult radiation experts: cathartics, activated charcoal, gastric lavage, and radionuclide-specific decorporation agents

Treatment of Internal contamination

- Not measured but calculated
- Calculations: by a health physicist on samples such as nasal swabs, urine, stool to estimate how much activity entered the body
- Committed doses: defined as the doses received that last more than 50 years because of the internal deposit of radionuclide

TABLE 10-8 Specimens for Medical Assessment

Specimen/Type of Analysis	Reason	Mechanism
Suspected radiation exposure		
Check a CBC every 6 h for 24–48 h	Establish baseline and assess lymphocyte depletion as an early predictor of dose.	Venipuncture
Serum amylase and CRP, repeat daily for 3 d	Parotid glands are sensitive to radiation; amylase will rise if exposed to >0.5 Gy.	Venipuncture
Blood: chromosomal analysis (dicentrics)	Gold standard for estimating dose.	Venipuncture. Call REAC/TS for assistance.
Urine: routine urinalysis	Establish baseline kidney function, especially if internal contamination is suspected.	Clean catch
Suspected external contamination		
Swabs of body orifices and samples from dressings/wounds	Assess internal contamination and identify radionuclide.	Use separate saline or water-moistened swabs to wipe the inside of each nostril, ear, and mouth.
Suspected internal contamination		
Urine bioassay: 24-h specimen; repeat for 4 d	Radionuclide identification	Standard specimen containers
Consider feces bioassay in consult with radiation expert		

Abbreviations: CRP = C-reactive protein; REAC/TS = Radiation Emergency Assistance Center/Training Site.

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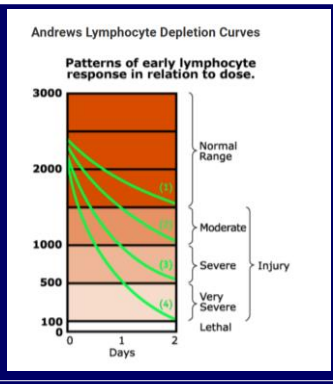

https://remm.hhs.gov/andrewslymphocytes.htm

TABLE 10-9 Internal Contamination Treatment

Radionuclide	Ionizing Radiation	Treatment	Mechanism of Action	Usual Administration
Iodine (I-131)	β, γ	Potassium iodide	Block thyroid uptake	130 milligrams PO for adults
Plutonium (Pu-239)	α	Ca-DTPA or Zn-DTPA	Chelation	1 gram in 250 mL NS or 5% dextrose in water over 60 min
Tritium (H-3)	β	Water	Dilution	Oral: 3–4 L a day for 2 wk
Cesium (Cs-137)	β, γ	Prussian blue	Decrease GI uptake	1 gram in 100–200 mL water three times a day for several days
Uranium (U-235)	α	Bicarbonate	Urine alkalinization	2 ampules in 1 L NS at 125 mL/h

Abbreviations: DTPA = diethylenetriamine pentaacetate; NS = normal saline.

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Box 30-7: Radiation: Poisoning Treatment Paradigm™

Alter Absorption: Decontamination (see Box 30-6)

Administer Antidotes
- Calcium and/or Zinc DTPA for internal contamination with
  - Americium
  - Curium
  - Plutonium
- Potassium iodide for internal contamination with
  - Iodine 125 and 131
- Prussian blue for internal contamination with
  - Cesium137
  - Thallium

Basics
- Continually reassess ABCs
- Treat accordingly

Change Catabolism
- Not applicable

Distribute Differently
- DTPA
- Potassium iodide
- Prussian blue

Enhance Elimination
- DTPA
- Potassium iodide
- Prussian blue
- Forced water intake and diuresis for tritium internal contamination

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Prenatal Exposures

- Factors: dose. gestational age
- Fetus: shielded in part by the uterus and surrounding tissues.
- Gamma and radiographs: directed toward a pregnant woman's abdomen could harm the fetus
- Before about 2 weeks: all-or-none phenomenon, > 0.1 Gy expected to be lethal

Prenatal Exposures

- 2-8 weeks: organogenesis occur, at risk for congenital malformations and growth retardation.
- After 8 weeks: increased risk of mental retardation and miscariage
- Consult with radiation medicine physicians regarding fetal dose estimation and risk assessment counseling for the expecting parents

- The REMM Scarce Resources Triage Tool: available onlin e for assistance in evaluating a patient's prognosis
- Contaminated bodies: should not be cremated because this will only redistribute the nuclear material, which is not destroyed by fire

Resources

Conclusions

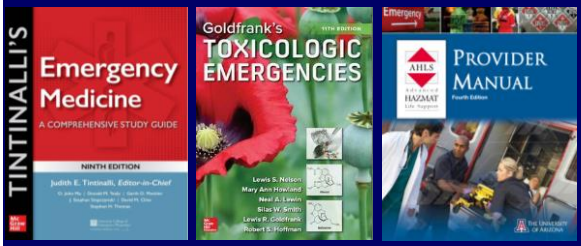
- Ioninzing radiation: irradiation, contamination, incorporation
- Clinical effects:

- Local Radiation Injury/ Cutaneous radiation injury

- Acute Radiation Syndrome

- Treatment of life-threatening injuries
- Decontamination, Decorporation

References



Thank you for your attention