



CRACKCast E146 – Radiation Injuries

Key concepts:

Patients contaminated with radiation pose very little risk to health care providers when appropriate precautions and decontamination procedures are employed.

- Decontamination should not delay or impede the stabilization of patients in radiation emergencies.
- Tissues with greater rates of cellular division, particularly the hematopoietic and gastrointestinal systems, are most radiosensitive.
- Vomiting and skin burns occurring shortly following radiation exposure are predictors of severe radiation injury.
- The 48-hour absolute lymphocyte count is the most important prognostic indicator and should be drawn on suspected radiation exposure patients.
 - Most therapy is supportive and symptomatic except for exposures involving the ingestion or inhalation of radioactive material, when specific therapy with blocking or chelating agents may be indicated.
- Formal consultation at the hospital, regional, and national levels is available 24 hours a day and should be used for assistance when any patient with radiation injuries is evaluated.

Core Questions:

1. How can radiation injury occur?
2. Compare non-ionizing radiation and ionizing radiation – give examples of each
3. What are the types of ionizing radiation that cause injury?
4. List 4 types of radiation with potential for contamination
5. List 3 routes of exposure to radiation
6. Describe common early symptoms of acute radiation syndrome (ARS). What clinical manifestations are predictive of severity of exposure and subsequent outcomes?
7. Describe prehospital and emergency department management of the radiation victim.
8. If there are limited resources in mass casualty, how can triage of radiation victims be divided?
9. What doses are generally fatal, potentially fatal (and produce significant symptoms) and are generally safe (minimal symptoms if any)?
10. What is the best laboratory test for predicting the outcome following a radiation exposure?

Rosens in Perspective:

Don't let this chapter give you PTSD - as you rack your brain to remember high school physics!

Let's get back to the basics so you can understand this! Just like thermal, electrical, and kinetic energies cause damage, radiation can as well! But usually in a less visible way...(unless you actually pick up a piece of highly radioactive material).

Think of *Radiation as energy that travels in the form of a particle or wave.*



It is produced by radioactive decay of an unstable atom (radionuclide or radioisotope) or by the interaction of a particle with matter. These substances give off radioactive ENERGY!

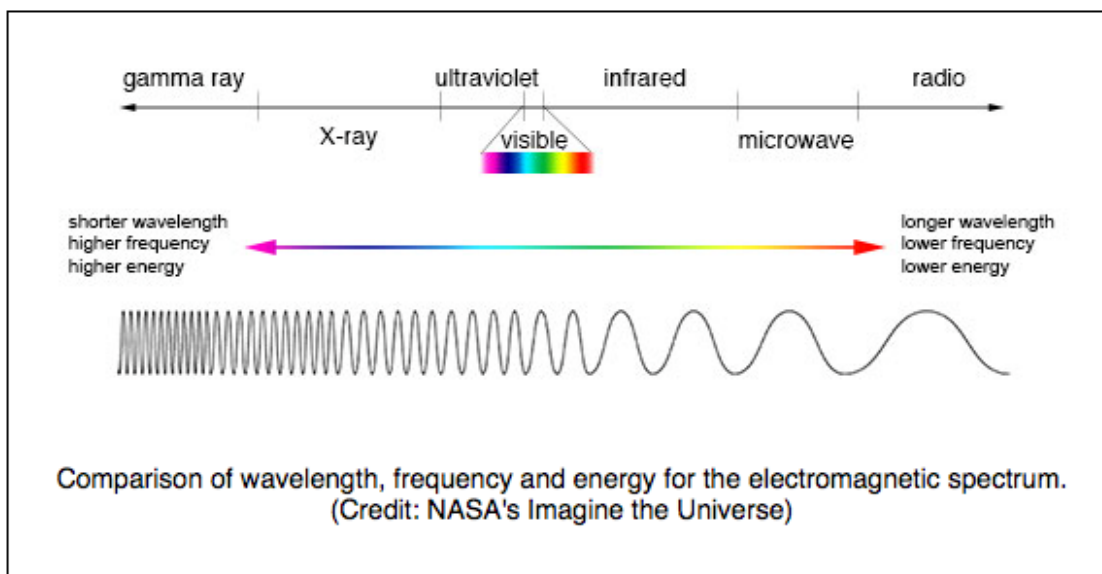
Particle radiation consists of particles that have mass and energy, and may carry an electric charge.

*Examples of particle radiation include alpha particles (helium nuclei), protons, beta particles (electrons ejected from the nucleus), and neutrons. **Think of your clothes being contaminated with fall out from the Fukushima disaster.***

The source of radiation energy is high frequency EMR.

*Electromagnetic radiation consists of photons that have energy but no mass or charge. Radiation can be either ionizing or nonionizing depending on its energy and ability to penetrate matter. **Think of a CT scanner technician who gets a constant small exposure to ionizing radiation daily (X-rays).***

Electromagnetic radiation varies by frequency and wave-length...as described in that familiar figure of the electromagnetic spectrum:



[1] How can radiation injury occur?

Like other forms of energy injury, radiation exposure can be external (eg, exposure to x-rays or a radiation burn to the hand) or internal, resulting from the inhalation, ingestion, or injection of radioisotopes.

The four different but interrelated units for measuring radiation (radioactivity, exposure, absorbed dose, and dose equivalent)



Table 138.1: Radiation Units Description and Conversion Factors

MEASURE	DESCRIPTION	UNITED STATES UNITS	INTERNATIONAL UNITS	CONVERSION
Radioactivity	Amount of ionizing radiation released by a material	Curie (Ci)	Becquerel (Bq)	1 Bq = 2.7×10^{-11} C
Exposure	Amount of radiation traveling through air	Roentgen (R)	Coulomb (C)/kg	1 C/kg = 3875.9 R
Absorbed dose	Amount of radiation absorbed by a person	Radiation absorbed dose (Rad)	Gray (Gy)	1 Gy = 100 rad
Dose equivalent (effective dose)	Combines the amount of radiation absorbed with the tissue damaging potential of the type of radiation	Roentgen equivalent man (Rem)	Sievert (Sv)	1 Sv = 100 rem

[2] Compare non-ionizing radiation and ionizing radiation – give examples of each

Think back to the electromagnetic spectrum we learned about in school....

	examples	Patho principles	
non-ionizing	<i>(near ultraviolet, infrared, microwaves, radio waves, and very or extremely low frequency radiation)</i>	<i>Damage depends on the frequency and wavelength and duration of exposure.</i>	<i>For example, ultraviolet light can produce sunburns, visible light (eg, lasers) can produce corneal and retinal burns, and microwaves can produce heating of body tissues; prolonged exposure may produce sensitivity in individuals prone to EHS</i>
ionizing	<i>Alpha particles, beta particles, and neutrons are examples of <u>particle ionizing radiation</u>. Only the <u>high frequency portion of the electromagnetic radiation</u> (gamma rays, x-rays, and far ultraviolet) has sufficient energy to produce ionization.</i>	<i>Ionizing radiation includes particles and photons that have sufficient energy to produce ionization of the atoms that they encounter. It damages tissue directly (by breaking your DNA) or indirectly by generating free radicals</i>	<i>Radon is the second leading cause of lung cancer in the USA. principles of radiation protection include time, distance, shielding, and quantity.</i>



	<p>Background radiation (radon, thoron, cosmic radiation, natural, and terrestrial)</p> <p>Medical procedures (CT, nuclear med, fluoroscopy, x-rays)</p> <p>Occupational and consumer sources</p>		
--	---	--	--

Note: ultraviolet radiation can be non-ionizing and ionizing depending on the wavelength

[3] What are the types of ionizing radiation that cause injury?

Electromagnetic radiation:

- Far ultraviolet (this is blocked by the ozone layer)
- X-rays

Particle radiation

- *Neutron radiation*
- *Alpha particles*
- *Beta particles*
- *Gamma rays (photons) - that penetrate much deeper*

Red = generally dangerous with internal exposure

Gamma and x-rays are high-energy photons that differ in their place of origin: gamma rays are emitted from the nucleus, whereas x-rays are produced as the result of changes in the positions of electrons orbiting the nucleus.

[4] List 4 types of radiation with potential for contamination

Anything that is ingested:

- Alpha particles
- Beta particles
- Gamma particles
- Radioisotopes that biodisposition into certain organs (e.g. radioiodine concentrating in the thyroid and resulting in thyroid cancer)

*The principles of radiation protection include **time** (reducing the time that you are exposed to radiation), **distance** (the intensity of radiation dose decreases inversely with the square of the distance), **shielding** (e.g. lead), and **quantity** (amount of a radioisotope in an area).*

The effectiveness of shielding varies with the type of the radiation. For example, alpha particles can be stopped by a thin piece of paper or even the dead cells in the outer layer of the skin, whereas thick, dense shielding is necessary to protect against gamma rays.



[5] List 3 routes of exposure to radiation

This is spaced repetition from question 1; but Rosen's describes three main processes:

- **Irradiation (e.g. external exposure of a person or object to a radioactive source)**
 - An object doesn't become radioactive unless neutron activation occurs. So, when a person is irradiated, such as a patient who has just received a CT scan or x-ray, no hazard exists to medical personnel who come into contact with the patient.
- **Contamination**
 - exposure to radioactive particulate matter (alpha and beta particles).
 - Contamination usually occurs externally but may be internal if the radioactive material is inhaled and deposited in the lungs.
 - Contamination is not an acute threat to the life of the patient or the provider, and its presence should not preclude institution of lifesaving measures. The radioactive particulate matter may emit radiation with an effect that is directly related to the time of exposure, distance from the source, and type of contamination.
- **Incorporation**
 - when a radioactive material is taken up by a tissue, cell, or organ. This can occur through ingestion, inhalation, or absorption via an open wound.
 - As in radioiodine therapy for an overactive thyroid or inhalation of radioactive material after bomb blast or reactor explosion

[6] Describe common early symptoms of acute radiation syndrome (ARS). What clinical manifestations are predictive of severity of exposure and subsequent outcomes?

Acute radiation syndrome (ARS) occurs after a patient is exposed to whole body radiation.

ARS can result from external or internal exposure to radiation and varies in nature and severity by dose, dose rate, dose distribution, and individual susceptibility.

In general, cells that are undifferentiated, divide quickly, and have high metabolic activity are most radiosensitive.

Examples of these types of cells include bone marrow stem cells, lymphocytes, spermatogonia, intestinal crypt cells, and epidermal basal cells.

In general, the severity of ARS depends on the amount of **radiation exposure** (measured in grays)



TABLE 138.2 Systemic Radiation Effects Based on Dose Adapted from The Medical Aspects of Radiation Incidents; originally published by ORISE and REAC/TS under contract number DE-AC05-06OR23100 between the US Department of Energy and ORAU, 2013.

Dose (gray)	12 +	→ Bone Marrow Suppression	Neurovascular syndrome onset	Multiple organ failure
	11			Probable death
	10			Consider stem cell transplants
	9			
	8			
	7		Gastrointestinal syndrome onset	LD 50/60 with supportive care
	6			
	5			LD 50/60 without treatment
	4			
	3			
	2		Hematopoietic syndrome onset	≈100% survival without treatment
	1			
	0			

There are three phases to ARS: prodromal, latent, and manifest illness.

1. Prodromal

- Nonspecific: anorexia, nausea, vomiting, and fatigue.
- This phase is useful to help predict the severity of the radiation injury.
- The presence, onset, and frequency of nausea and vomiting, although ***nonspecific, can serve as a prognostic factor. Early onset of nausea and vomiting, the persistence of it, and the presence of diarrhea indicates a severe radiation injury.***



2. **Latent - initial symptom resolution**
 - **This step is skipped with people receiving a lethal dose of radiation**
3. **Manifest illness phase**
 - **Hematopoietic sub-syndrome**
 - the first sub-syndrome seen as the hematopoietic system is the most radiosensitive.
 - This sub-syndrome can appear at doses greater than 1 Gy and typically results in bone marrow suppression. At doses less than 1 Gy (100 rem), most cells survive but may be susceptible to radiation induced cancer.
 - Lymphocyte depletion is the first cell line to decrease and with high doses of radiation the drop will occur sooner and with greater severity.
 - **GI sub-syndrome**
 - begins to occur at doses nearing 6 Gy about 1 week after exposure. Patients will display nausea, vomiting, gastrointestinal bleeding, malabsorption, and massive fluid losses potentially leading to hypovolemia and cardiovascular collapse.
 - These symptoms are due to death of the intestinal epithelial precursor cells and resultant denuding of the intestinal epithelial surface. Thrombocytopenia and immunosuppression from the accompanying hematopoietic sub-syndrome predisposes patients to infection and bleeding.
 - **Neurovascular sub-syndrome**
 - **High doses of radiation, usually lethal**
 - irritability, altered mental status, seizures, prostration, ataxia, and hypotension. Coma and death usually occur within a few hours. Because of the high dose of radiation needed to produce these findings, patients often die before progressing to the latent phase.

The effects of radiation can be deterministic or stochastic. Deterministic effects are those in which the severity of injury is a function of dose (eg, bone marrow suppression). Stochastic or probabilistic effects are those in which the probability of an effect, rather than its severity, is a function of dose. An example of a stochastic effect is the development of radiation-induced cancer.

[7] Describe prehospital and emergency department management of the radiation victim.

Prehospital:

- Activate / call your local disaster plan expert / administrator
 - Information should be gathered regarding the exposure event: the numbers and types of patients potentially affected, the radionuclide involved, the route of exposure, and the estimated dose of radiation.
- Treat immediate life threats!
 - Unstable patients should be rapidly transported in lieu of decontamination measures. Radio contact with the receiving hospital should be provided to facilitate preparations. If the community disaster plan has a designated hospital for radiation-contaminated victims, patients should be transported directly to that facility, bypassing hospitals less equipped to care for these complicated patients.



- Decontamination should be initiated at the scene. Patients with abnormal vital signs should have partial decontamination, such as clothing removal, at the scene before expeditious transportation to an ED.

ER:

1. Preparation

- Hopefully there has been some prehospital notification and activation of the disaster process
 - Number of patients and types of injuries
 - Roles clearly assigned - “I FLOP approach”
 - Radiation officer to minimize spread of contamination
 - Media relations person
- Decontamination area

2. External contamination management:

- Radiation contamination is not an acute threat to the life of the patient or the provider, and its presence should not preclude institution of lifesaving measures. If standard precautions are taken, the risk to the health care providers is minimal.
 - E.g. of Alexander Litvinenko - 3 weeks of health care worker contact and no harms reported to the HCWs
- Think of it like the person who just had a CT scan and was “irradiated”
- 90% of the radiation from the patient can be removed by taking off their clothing and shoes and placing them in plastic bags - soap and water to wash down skin will help further. High pressure, repeat cleaning methods may be required
- Universal precautions, including rubber gloves, shoe covers, and respirators if airborne contamination is suspected, are effective in protecting personnel and the work area from contamination. **The only variation is to wear two sets of gloves and to change the outer pair when appropriate to avoid cross-contamination.**
- **Assess for Local and Acute Radiation syndrome**
- Local radiation injury = treat like a burn and refer to a burn centre within 72 hrs:
 - Due to the chronic vascular injury and the potential for even minor trauma to the area to recapitulate the injury, the following are important in the treatment of LRI: topical corticosteroids, hyperbaric oxygen (HBO) therapy, pentoxifylline and vitamin E therapy, and appropriate wound care.

3. Internal contamination

- If a patient is externally contaminated, they have a higher risk of being internally contaminated. For internally contaminated patients, management should focus on decreasing absorption, enhancing elimination, and blocking distribution to target organs.
- Treatment directed at internal contamination by particular radionuclides can include potassium iodide for radioactive iodine exposures, bicarbonate for uranium, Prussian blue for cesium and DTPA for plutonium and transuranics
 - See Table 138.5 with a list of the radionuclides of interest with their associated treatment options
- Assess for Acute Radiation Syndrome

Recap (follow in Figure 138.3)



For more:

- **Canadian response links/plans**
 - <http://nuclearsafety.gc.ca/eng/resources/emergency-management-and-safety/index.cfm>
 - **24 hr CNSC duty officer telephone line:**

Phone 613-995-0479, the CNSC duty officer emergency telephone line, in the event of an emergency involving a nuclear facility or radioactive materials, including:

- *any accident involving a nuclear reactor, nuclear fuel facility, or radioactive materials*
- *lost or damaged radioactive materials*
- *any threat, theft, smuggling, vandalism or terrorist activity involving a nuclear facility or radioactive materials*

The CNSC Duty Officer emergency telephone line is available 24 hours a day, 7 days a week.

- **BC Emergency Info:**
 - <https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery>

[8] If there are limited resources in mass casualty, how can triage of radiation victims be divided?

Given the limited resources casualties can be divided by:

- **Time to nausea, vomiting, diarrhea**
 - Those with near immediate gastrointestinal symptoms have likely suffered a fatal dose (e.g. if time to vomiting is < 1 hour)
 - *Patients who experience vomiting within 2 hours of exposure will require hospitalization and careful medical observation, because they are likely to have sustained life-threatening doses of radiation.*
- **Development of neurovascular sub-syndrome** within the first 24 hours should be provided comfort care measures because they likely were exposed to a lethal amount of radiation

[9] What doses are generally fatal, potentially fatal (and produce significant symptoms) and are generally safe (minimal symptoms if any)?

Fatal: > 10 Gy

Possibly fatal: > 5 Gy

Generally safe: < 2 Gy

See Table 138.2 (Question 6)



[10] What is the best laboratory test for predicting the outcome following a radiation exposure?

Quantifying the absorbed dose of radiation can be challenging, especially in the emergency department (ED).

Information on the radiation source, field strength, time of exposure, distance, shielding, and routes of exposure is often incomplete. Although radiation doses can be reconstructed at a later time by health physicists, emergency clinicians will most often rely on biodosimetry tools, such as time to vomiting and lymphocyte depletion kinetics.

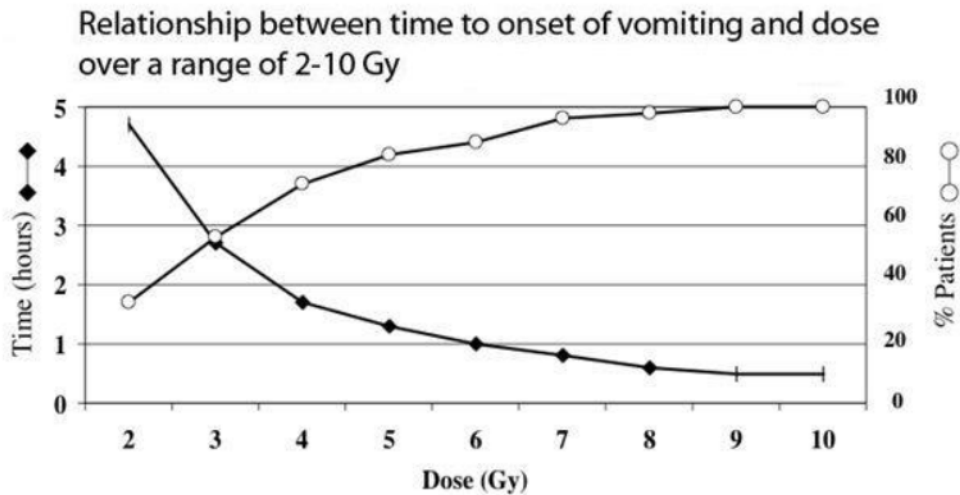
These online tools are available at www.remm.nlm.gov/ars_wbd.htm#vomit

Best test at predicting outcome:

- **Lymphocyte depletion kinetics - ABSOLUTE LYMPHOCYTE COUNT**
 - *The 48-hour absolute lymphocyte count is the most important prognostic indicator and should be drawn on all suspected radiation exposure patients. Levels greater than 1200/ μ L indicate a clinically insignificant dose of radiation and an excellent prognosis. Levels less than 500/ μ L indicate a significant and possible lethal exposure.*
 - *A baseline complete blood count (CBC) with differential and absolute lymphocyte count should be obtained and repeated every 6 hours for the first 24 hours and at least daily thereafter.*
 - *The absolute lymphocyte count at 48 hours after exposure is a good predictor of radiation injury (Fig. 138.2). If the absolute lymphocyte count is greater than 1200 cells/ μ L, it is unlikely that the patient has received a clinically significant dose of radiation. If the absolute lymphocyte count falls between 100 and 500 cells/ μ L at 48 hours, a significant or even lethal dose of radiation should be suspected. A level in this range is an indication for neutropenic precautions. Weeks later, thrombocytopenia and anemia may develop because these cell lines are more radioresistant.*

BEST CLINICAL TEST = TIME TO ONSET OF VOMITING:

- **Be worried if after a radiation exposure the patient starts vomiting within the first 6 hours! (this suggests an exposure of at least 1.9 Gray**



Notes on the graph above:

- Left y-axis reflects time (in hours) to onset of vomiting after a radiation event.
- Right y-axis reflects percent of patients expected to vomit at a particular radiation dose.
- X-axis reflects estimated whole body dose received (measured in gray).

https://www.remm.nlm.gov/ars_wbd.htm#vomit_section

Other tests:

- Contamination survey instrument:
 - *Geiger Muller detector: These detectors measure the presence of radioactive material in counts per minute.*
 - *Field strength devices - used to measure radiation fields at the event scene (done by radiation experts/nuclear physicists)*