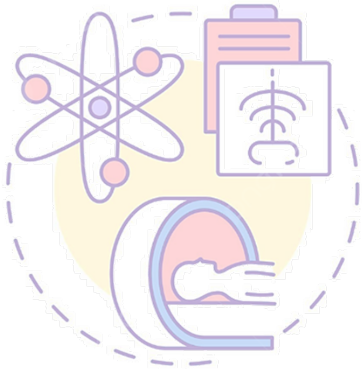
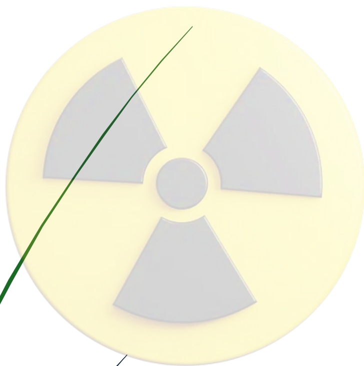
Radiation Protection

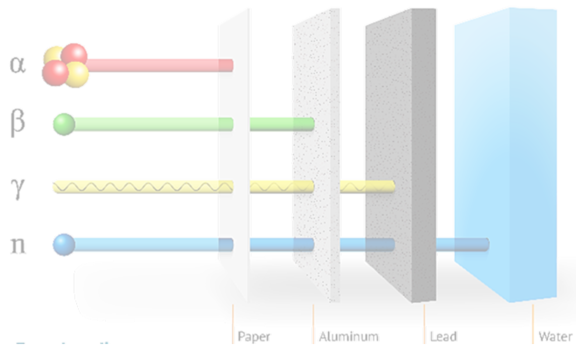
The Second Stage

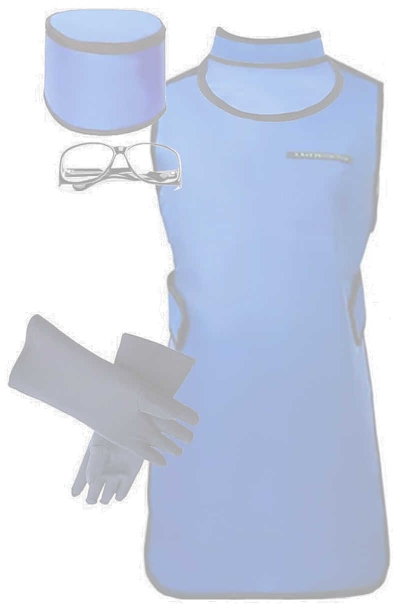
First Semester – Lecture No. 4,5

2025 - 2026









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Radiation Measurement Units

OUTLINES:

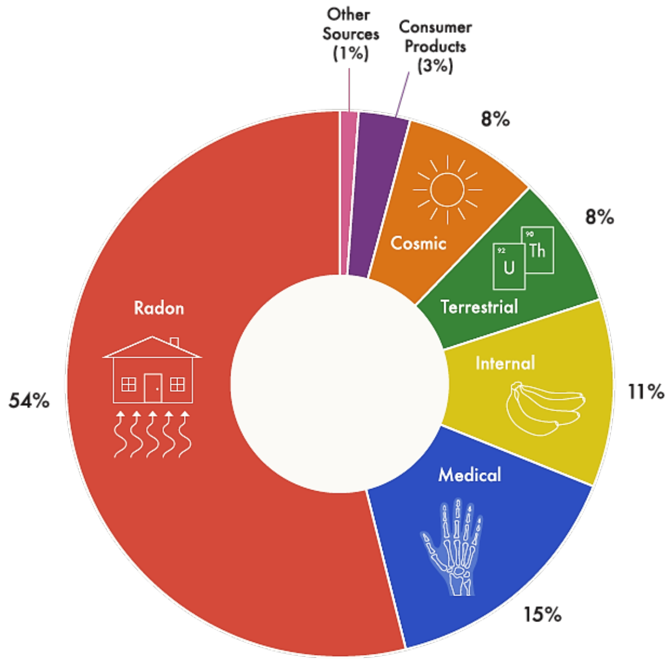
- ✓ **System of Physics Units.**
- ✓ **Radiation Units.**
- ✓ **Exposure Units.**
- ✓ **Absorbed Dose.**
- ✓ **Equivalent Dose.**
- ✓ **Effective Dose.**

- ➢ **Background Radiation.**
- ➢ **Peak Skin Dose.**
- ➢ **ALARA principles.**
- ➢ **Exposure doses for occupational, patients and public.**
- ➢ **Dose limits:**
  - ♦ **Maximum permissible occupational dose.**
  - ♦ **Occupational and non-occupational exposure – limit dose.**
  - ♦ **Maximum permissible public dose.**
  - ♦ **Maximum permissible Patient dose.**
  - ♦ **Whole body, tissues and organs dose limits.**

What is Background Radiation?

Background radiation is a measure of the level of ionizing radiation present in the environment at a particular location that is not due to the deliberate introduction of radiation sources (لا يرجع إلى الإدخال المتعمد لمصادر الإشعاع).

Background radiation originates from a variety of sources, **both natural and artificial.** These include both cosmic radiation and environmental radioactivity from naturally occurring radioactive materials (such as radon and radium), as well as man-made medical X-rays, fallout from nuclear weapons testing and nuclear accidents.



Radon gas is the most background radiation present as the figure describes it. Radon is a chemical element; it has symbol ***Rn*** and atomic number 86. It is a radioactive noble gas and is colorless and odorless. Of the three naturally occurring radon isotopes, only ^{222}Rn has a sufficiently long half-life (3.825 days) for it to be released from the soil and rock where it is generated.

- **Peak Skin Dose.**

Peak Skin Dose (PSD) is the highest dose of radiation absorbed by a single, localized area of a patient's skin during a medical imaging procedure.

The maximum absorbed dose to the most heavily exposed localized region of skin (defined as the localized region of skin that lies within the primary x-ray beam for the longest period or multiple exposures during a fluoroscopically guided procedure). The notation used by the International Commission on Radiation

Units and Measurements for this quantity is ***D-skin; it is also referred to as D-skin, max.*** Peak skin dose is measured in units of ***Gy***.

The peak skin dose (PSA) is the most important quantity to determine because it estimates the risk of deterministic effects and injury, so it is the highest dose for a single area of the skin.

Deterministic effects التأثيرات الحتمية describe a cause-and-effect relationship between ionizing radiation and certain side effects. They are also known as non-stochastic effects to contrast them with chance-like stochastic effects (e.g., cancer induction).

"Non-stochastic effects" is an older term for what is now most commonly referred to as "deterministic effects."

	Non-stochastic (deterministic) effects	Stochastic effects
Threshold	Yes, a threshold dose must be exceeded.	No, it is assumed that any dose carries some risk.
Severity	Increases with dose.	Is independent of the dose.
Incidence	The effect is certain to happen if the dose is high enough.	The probability of the effect increases with dose.
Mechanism	Killing or severe damage to a large number of cells.	Damage to a single cell's DNA, leading to a mutation.
Example	Skin burns, sterility, radiation sickness.	Cancer, genetic mutations.

These effects depend on the dose, dose rate, dose fractionation, irradiated volume, and type of radiation.

How is PSD measured and estimated?

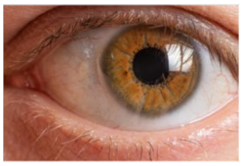
Precisely measuring PSD in real-time is difficult in a clinical setting because it depends on multiple variables, such as the position of the x-ray beam, gantry angles, and patient anatomy. Instead, PSD is usually calculated or estimated using one of the following methods: 1- Direct measurements such as Radiochromic film or thermoluminescent dosimeters (TLDs); 2- Indirect estimation such as dose tracking software.

Deterministic effects have a *threshold* below which they do not occur. The *threshold* may be very low and may vary from person to person. However, once the threshold has been exceeded, the severity of an effect increases with the dose.

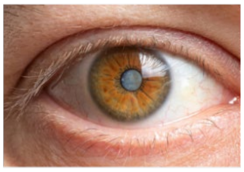
Examples of Deterministic Effects (doses are given as absorbed doses and expressed in grays (Gy)):

- skin erythema: 2-5 Gy
- irreversible skin damage: 20-40 Gy
- hair loss: 2-5 Gy
- sterility: 2-3 Gy
- cataracts: 0.5 Gy
- lethality (whole-body): 3-5 Gy
- fetal abnormality: 0.1- 0.5 Gy

Skin erythema



Normal Eye



Cataract Eye

RADIATION DOSES Millisieverts (mSv)

10,000	Acute radiation poisoning - death within weeks
6,000	Typical dose received by Chernobyl nuclear plant workers who died within one month of accident
3,000	Survival rate approximately 50 percent
2,200	Reading found near tanks used to store radioactive water at Fukushima plant, Sep 3, 2013
1,000	Causes radiation sickness and nausea, but not death. Likely to cause fatal cancer many years later in about 5 of every 100 persons exposed
700	Vomiting, hair loss within 2-3 weeks
500	Allowable short-term dose for emergency workers taking life-saving actions
400 per hour	Peak radiation level recorded inside Fukushima plant four days after accident
350 per lifetime	Exposure level used as criterion for relocating residents after Chernobyl accident
250	Allowable short-term dose for workers controlling 2011 Fukushima accident
100	Lowest level linked to increased cancer risk
20 per year	Average limit for nuclear industry workers
10	Full-body CT scan
2.4 per year	Person's typical exposure to background radiation
0.01	Dental x-ray

❖ **ALARA principles**

What is the ALARA Principle?

ALARA is an acronym used in radiation safety for "**As Low As Reasonably Achievable**." منخفضة بقدر ما يمكن تحقيقه بشكل معقول."The ALARA radiation safety principle is based on the minimization of radiation doses and limiting the release of radioactive materials into the environment by employing all "reasonable methods." ALARA is not only a sound radiation safety principle, but it is a regulatory requirement for all "radiation protection programs." The ALARA concept is an integral part of all activities involving the use of radiation or radioactive materials, helping to prevent both unnecessary and excessive exposure. The three major principles to assist with maintaining doses "As Low As Reasonably Achievable" are ***time, distance and shielding***.

How can you reduce external radiation exposure?

1. Time

Reducing the time of exposure can directly reduce radiation dose. Dose rate is the total amount of radiation absorbed relative to its biological effect. Dose rate is the rate at which the radiation is absorbed. Limiting the time of radiation exposure will reduce your radiation dose.

2. Distance

Increasing the distance between you and the radiation source you will reduce exposure by the square of the distance. Doubling the distance between your body and the radiation source will divide the radiation exposure by a factor of 4.

3. Shielding

Lead or lead equivalent shielding for X-rays and gamma rays is an effective way to reduce radiation exposure. There are various types of shielding used in the reduction of radiation exposure including lead aprons, mobile lead shields, lead glasses, and lead barriers. When working in radiation areas it is important to use shielding whenever possible.

How can you reduce internal radiation exposure?

1. Good Hygiene

Practicing good hygiene and housekeeping habits effectively moderates the internal radiation hazards presented by radionuclides. By eliminating the presence of food and drink in areas where radioactive materials are used or stored and controlling "hand-to-mouth" habits, the risk of internal radiation exposure is reduced.

2. Control of Contamination

Labeling radioactive and potentially radioactive areas and items will help prevent the spread of contamination. It is important to control contamination with absorbent papers and spill trays and placing any contaminated item in a properly labeled waste container. When contamination occurs, it is important to promptly decontaminate the area to prevent the spread of contamination.

3. Airborne Hazards

Using fume hoods and avoiding dust, aerosol, or volatile gas production can reduce the potential for inhalation of radioactive substances.

4. Use Proper PPE

Using the proper personal protective equipment (PPE) such as disposable gloves, safety glasses, lab coats, etc. will help reduce the possibility of ingestion or absorption of radioactive materials.

It's very important to understand how to protect your medical staff and patients when working around high frequency radiation and to be aware of ways to reduce the level of radiation exposure. It takes a team effort to successfully implement the ALARA principles. ALARA should be a routine element of your work in radiological areas.

Dose limits:

1- **Maximum Permissible Occupational Doses**الحد الأقصى المسموح به للجرعات المهنية

Definition:

Occupational Doses: is the internal and external dose of ionizing radiation received by workers in the course of employment in such areas as fuel cycle facilities, industrial radiography, nuclear medicine, and nuclear power plants.

You can define it as "the dose received by an individual in a restricted area or while performing assigned duties that involve exposure to sources of radiation".

So, the workers in fields use radioactive sources are exposed to varying amounts of radiation, depending on their jobs and the sources with which they work.

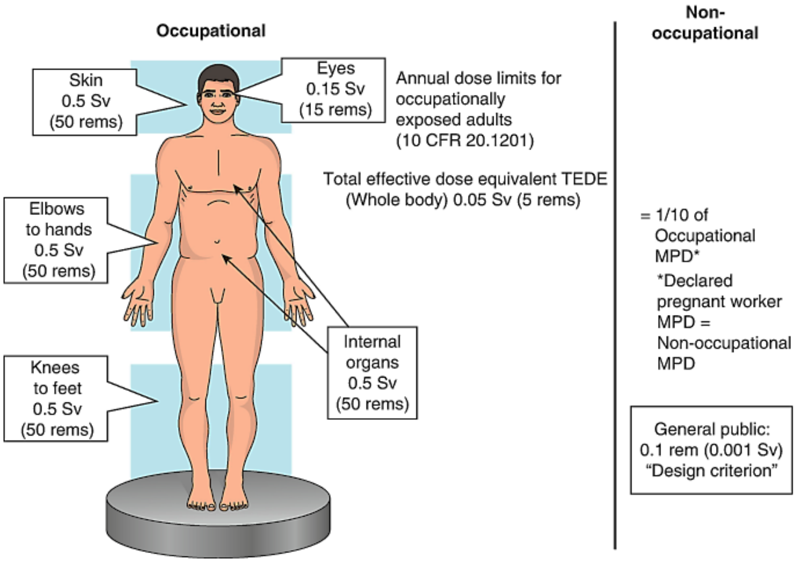
The Nuclear Radiology Commission (NRC) licenses to limit occupational exposure to 5,000 mrem (50 mSv) per year.

The limits vary depending on the affected part of the body. The annual total for the whole body is 5,000 mrem. The next table explains limits dose related to part of body.

Organ, tissue	Occupational Dose Limits		Non-occupational Dose Limits	
	mrem/year	mSv/year	mrem/year	mSv/year
Whole Body	5,000	50	100	1
Lense of the eye	15,000	150	NA	NA
Shallow dose (skin and extremities)	50,000	500	NA	NA

Occupational and non-occupational (public) exposure limit dose:

The dose limit to non-occupational workers and members of the public are set at two percent of the annual occupational dose limit. Therefore, exposure to a non-radiation worker must not exceed 100 mrem/year. This exposure would be in addition to the annual background radiation.



How do you calculate occupational limit dose?

- For whole-body dose limit is assumed to be at the deep-dose equivalent (a tissue depth of 1 cm).
- For lens dose equivalent is the dose equivalent to the lens of the eye from an external source of ionizing radiation at a tissue depth of 0.3 cm.

- For shallow-dose equivalent is the external dose to the skin of the whole-body or extremities from an external source of ionizing radiation at a tissue depth of 0.007 cm averaged over and area of 10 cm^2.

Whole Body (DDE)	5 rem	5,000 mrem
Eyes (LDE)	15 rem	15,000 mrem
Extremities	50 rem	50,000 mrem
Skin (SDE)	50 rem	50,000 mrem
Fetal (gestation period)	0.5 rem	500 mrem
Gen. Public*	0.1 rem	100 mrem

2- Maximum possible public dose

The maximum permissible dose (MPD) is the upper limit of allowed radiation dose that one may receive without the risk of significant side effects.

The annual whole-body dose limit for physicians is 50 mSv. For the fetus, the annual maximum permissible dose is 0.5 rem or 5 mSv. Assuming proper techniques and well-functioning equipment, the scattered radiation dose to the patient and the medical personnel should be less than the above radiation doses. Reduction of the amount of radiation implies proper selection of the type of examination and imaging modality in order to minimize the exposure to the patient and personnel. The principle involved in reducing the amount of radiation is as low as reasonably achievable (ALARA) or as low as reasonably practicable (ALARP). This implies that in the process of obtaining good, usable images for the procedure, all steps are taken to minimize extraneous radiation exposure.

3- The maximum permissible patient doses

Much of the focus on radiation protection about 2 decades ago accrued from the need for protection of radiation *workers* and *collective doses to populations* from medical exposures.

The patients being the focus for any medical diagnosis, dose evaluation and diagnostic reference levels for patients are recognized as important tools for optimization of patient radiation protection.

In some cases, the patient may receive an incorrect dose which can jeopardize the quality of diagnosis. Therefore, the doses in radiation procedures need to be regularly evaluated to ensure the patients' safety and quality of medical images, he added.

Definition: Dose Length Product (DLP) is a proxy for the total absorbed dose in a phantom over the length of a scan.

DLP is useful for comparing exam doses if scan lengths are equivalent. DLP is measured in milligray-centimeter (mGy-cm).

CT	D_{air} (mGy)	$CTDI_w$ (mGy)	DLP (mGy cm)
Skull	29.8	22.5	349
Brain	59.5	45.0	540
Orbit	29.8	22.5	158
Skull base	29.8	22.5	68
Paranasal sinus	19.6	14.9	156
Mandible	19.6	14.9	60
Neck	29.8	22.5	315
Thorax	27.2	12.6	308
Thorax (middle third)	27.2	12.6	107
Upper abdomen	25.0	11.3	180
Pancreas	25.0	11.3	84
Pelvis	25.0	11.3	292
Whole abdomen	25.0	11.3	473
Lumber spine (L1–L5)	43.8	20.3	295
Lumbar spine (L3–L5)	43.8	20.3	162
Os sacrum	43.8	20.3	264

Definitions

1. Annual limit on intake (ALI) of radiation dose- the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the "reference man" that would result in a committed effective dose equivalent of 0.05 Sv (5 rem) or a committed dose equivalent of 0.5 Sv (50 rem) to any individual organ or tissue.
2. Dose equivalent - the product of the absorbed dose in tissue and the quality factor (a value that reflects the biological impact of a particular type of ionizing radiation). Measured in rem or Sievert (Sv).
3. Occupational dose - the dose received by an individual in a restricted area or while performing assigned duties that involve exposure to sources of radiation.
4. Member of the public - an individual who is not in a restricted area and who is not performing assigned duties that involve exposure to sources of radiation.
5. Committed dose equivalent (CDE)مكافئ الجرعة الملتزم به - the dose equivalent to organs or tissues of reference that will be received from an intake of radioactive material by an individual during the 50-year period following intake.

6. Committed effective dose equivalent (CEDE) - the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent (CDE) to each of these organs or tissues. This is a measure of the overall risk associated with internal deposition of radioactive material.
7. Eye dose equivalent (LDE) - the dose equivalent to the lens of the eye at a tissue depth of 0.3 cm (300 mg/cm^2).
8. Shallow dose equivalent (SDE) - the dose equivalent at a tissue depth of .007 cm (7 mg/cm^2) averaged over 1 cm^2; applies to external whole body or extremity exposure.
9. Deep dose equivalent (DDE) - the dose equivalent at a tissue depth of 1 cm; applies to external exposure.
10. Total Effective Dose Equivalent (TEDE) - the sum of the deep dose equivalent (DDE) for external exposures and the committed effective dose equivalent (CEDE) for internal exposures.
11. Total Organ Dose Equivalent, Maximum Organ (TODE) - the sum of the deep dose equivalent (DDE) and the committed dose equivalent (CDE) to the organ receiving the highest dose.

1) الحد السنوي للجرعة الممتصة (ALI) من الإشعاع - الحد المشتق لكمية المادة المشعة التي تدخل جسم عامل بالغ عن طريق الاستنشاق أو الابتلاع في عام واحد. الحد السنوي للجرعة الممتصة هو أصغر قيمة لجرعة مشعة معينة يدخلها "الرجل المرجعي" في عام واحد والتي من شأنها أن تؤدي إلى جرعة فعّالة ملتزمة تعادل 0.05 سيفرت (5 ريم) أو جرعة ملتزمة تعادل 0.5 سيفرت (50 ريم) لأي عضو أو نسيج فردي.

2) الجرعة المكافئة - حاصل ضرب الجرعة الممتصة في الأنسجة وعامل الجودة (قيمة تعكس التأثير البيولوجي لنوع معين من الإشعاع المؤين). يقاس بالريم أو سيفرت.(Sv)

3) الجرعة المهنية - الجرعة التي يتلقاها فرد في منطقة محظورة أو أثناء أداء مهام محددة تتضمن التعرض لمصادر الإشعاع.

4) عضو من عامة الناس - فرد ليس في منطقة محظورة ولا يؤدي مهام محددة تتضمن التعرض لمصادر الإشعاع.

5) مكافئ الجرعة الملتزمة - (CDE) مكافئ الجرعة للأعضاء أو الأنسجة المرجعية التي سيتلقاها الفرد من تناول مادة مشعة خلال فترة الخمسين عامًا التالية للتناول.

6) مكافئ الجرعة الفعالة الملتزمة - (CEDE) مجموع حاصل ضرب عوامل الترجيح المطبقة على كل من أعضاء الجسم أو الأنسجة التي تتعرض للإشعاع ومكافئ الجرعة الملتزمة (CDE) لكل من هذه الأعضاء أو الأنسجة. هذا مقياس للمخاطر الإجمالية المرتبطة بالترسب الداخلي للمواد المشعة.

7) مكافئ الجرعة للعين - (LDE) مكافئ الجرعة لعدسة العين على عمق أنسجة 0.3 سم (300 مجم/سم^2).

8) مكافئ الجرعة الضحلة - (SDE) مكافئ الجرعة على عمق أنسجة 0.007 سم (7 مجم/سم^2) بمتوسط 1 سم^2؛ ينطبق على التعرض الخارجي للجسم بالكامل أو الأطراف.

9) مكافئ الجرعة العميقة - (DDE) مكافئ الجرعة على عمق أنسجة 1 سم؛ ينطبق على التعرض الخارجي.

10) مكافئ الجرعة الفعالة الكلية - (TEDE) مجموع مكافئ الجرعة العميقة (DDE) للتعرضات الخارجية ومكافئ الجرعة الفعالة الملتزم بها (CEDE) للتعرضات الداخلية.

11) مكافئ الجرعة الكلية للأعضاء، أقصى عضو - (TODE) مجموع مكافئ الجرعة العميقة (DDE) ومكافئ الجرعة الملتزم بها (CDE) للعضو الذي يتلقى أعلى جرعة.