MODERN RADIOLOGY
eBook

Principles of Radiation Biology and Radiation Protection

EUROPEAN SOCIETY OF RADIOLOGY

Preface

Modern Radiology is a free educational resource for radiology published online by the European Society of Radiology (ESR). The title of this second, rebranded version reflects the novel didactic concept of the ***ESR eBook*** with its unique blend of text, images, and schematics in the form of succinct pages, supplemented by clinical imaging cases, Q&A sections and hyperlinks allowing to switch quickly between the different sections of organ-based and more technical chapters, summaries and references.

Its chapters are based on the contributions of over 100 recognised European experts, referring to both general technical and organ-based clinical imaging topics. The new graphical look showing Asklepios with fashionable glasses, symbolises the combination of classical medical teaching with contemporary style education.

Although the initial version of the ***ESR eBook*** was created to provide basic knowledge for medical students and teachers of undergraduate courses, it has gradually expanded its scope to include more advanced knowledge for readers who wish to 'dig deeper'. As a result, ***Modern Radiology*** covers also topics of the postgraduate levels of the *European Training Curriculum for Radiology*, thus addressing postgraduate educational needs of residents. In addition, it reflects feedback from medical professionals worldwide who wish to update their knowledge in specific areas of medical imaging and who have already appreciated the depth and clarity of the ***ESR eBook*** across the basic and more advanced educational levels.

I would like to express my heartfelt thanks to all authors who contributed their time and expertise to this voluntary, non-profit endeavour as well as Carlo Catalano, Andrea Laghi and András Palkó, who had the initial idea to create an ***ESR eBook***, and - finally - to the ESR Office for their technical and administrative support.

Modern Radiology embodies a collaborative spirit and unwavering commitment to this fascinating medical discipline which is indispensable for modern patient care. I hope that this ***educational*** tool may encourage curiosity and critical thinking, contributing to the appreciation of the art and science of radiology across Europe and beyond.

Minerva Becker, Editor
Professor of Radiology, University of Geneva, Switzerland

Principles of **Radiation Biology** and **Radiation Protection**

CHAPTER OUTLINE:

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/ Signage

<■> **CORE KNOWLEDGE**

>■< **FURTHER KNOWLEDGE**

<!> **ATTENTION**

>|< **COMPARE**

<?> **QUESTIONS**

<↑> **HYPERLINKS**

<∞> **REFERENCES**

CHAPTER OUTLINE:

MODERN RADIOLOGY eBook

Based on the ESR Curriculum for Radiological Education

Principles of **Radiation Biology** and **Radiation Protection**

CHAPTER OUTLINE:

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/ Credits

Most figures and part of the text included in this eBook chapter are based on an e-learning module that was produced by the the teams of Radiation Protection and Medical Physics of the Geneva University Hospitals (Hôpitaux Universitaires de Genève, HUG, Geneva, Switzerland), the Lausanne University Hospital (Centre Hospitalier Universitaire Vaudois, CHUV, Lausanne, Switzerland) and the University Hospital Zurich (Universitätsspital Zürich, USZ, Zürich, Switzerland).

The illustrations for the above-mentioned e-learning module were created by Rosaria Marraffino (Rosaria Marraffino, Learning and Communication for e-learning). The illustrations for the current e-Book chapter were adapted with the permission of all three university hospitals and of Mrs Rosaria Marraffino.

<∞> REFERENCES

https://www.hug.ch/
https://www.chuv.ch/fr/chuv-home
https://www.usz.ch/
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Chapter Outline

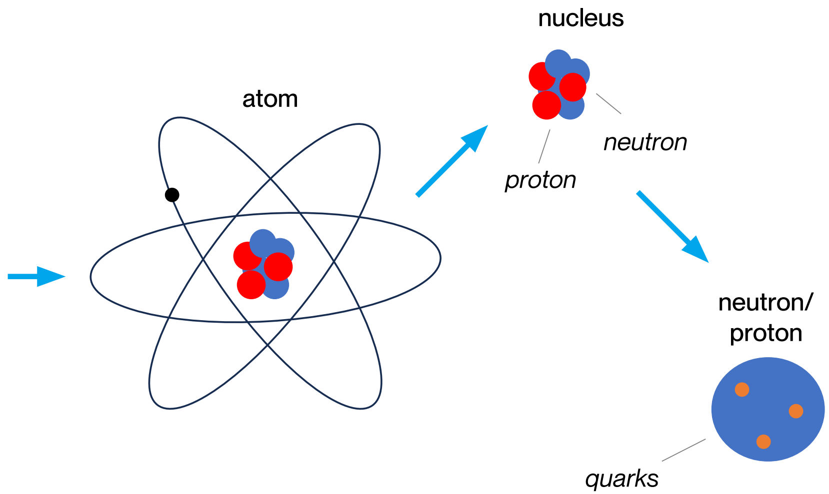
Ionising Radiation

CHAPTER OUTLINE:

/ Constituents of Matter

Matter is composed of molecules, which form solids, liquids or gases. Molecules are composed of atoms. **Atoms** are the smallest units of matter that retain all chemical properties of an element. Atoms consist of **protons** (positive charge, +1) and **neutrons** (no charge) located in the nucleus and **electrons** (negative charge, -1) located on orbitals surrounding the nucleus. Protons and neutrons have about the same mass (1.67×10^{-24} grams), which is defined as one atomic mass unit (amu) or one Dalton. Atoms are electrically neutral.

Quarks are subatomic particles without structure, which make up protons and neutrons. Each proton and each neutron has 3 quarks.



/ Electromagnetic Waves (EMW)

Electromagnetic waves (EMW) are a form of energy that travels through space at the speed of light. They consist of **oscillating electric and magnetic fields** that propagate perpendicular to each other and to the direction of the wave's travel.

EMW cover a **broad spectrum**, including radio waves, microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays. X-rays are EMW produced in an X-ray tube.

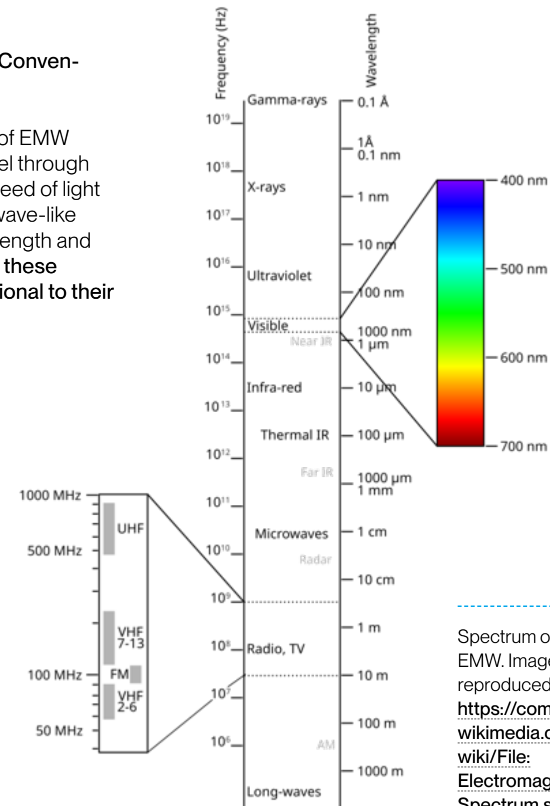
> See eBook chapter on Conventional X-Ray Imaging.

Common characteristics of EMW include their ability to travel through a vacuum, their speed (speed of light in a vacuum, c) and their wave-like properties, such as wavelength and frequency. **The energy of these waves is directly proportional to their**

<!> ATTENTION

$$Wavelength = \frac{speed\ of\ light\ in\ vacuum\ (c = 300\ 000 km/s)}{frequency}$$

- **Radiation = energy in motion.**
- **Electromagnetic radiation** or "electromagnetic rays" (travel at the speed of light) must be distinguished from **particulate matter radiation** or "matter rays" (travel at less than speed of light).
- Matter rays include electrons, protons, alpha particles, neutrons.

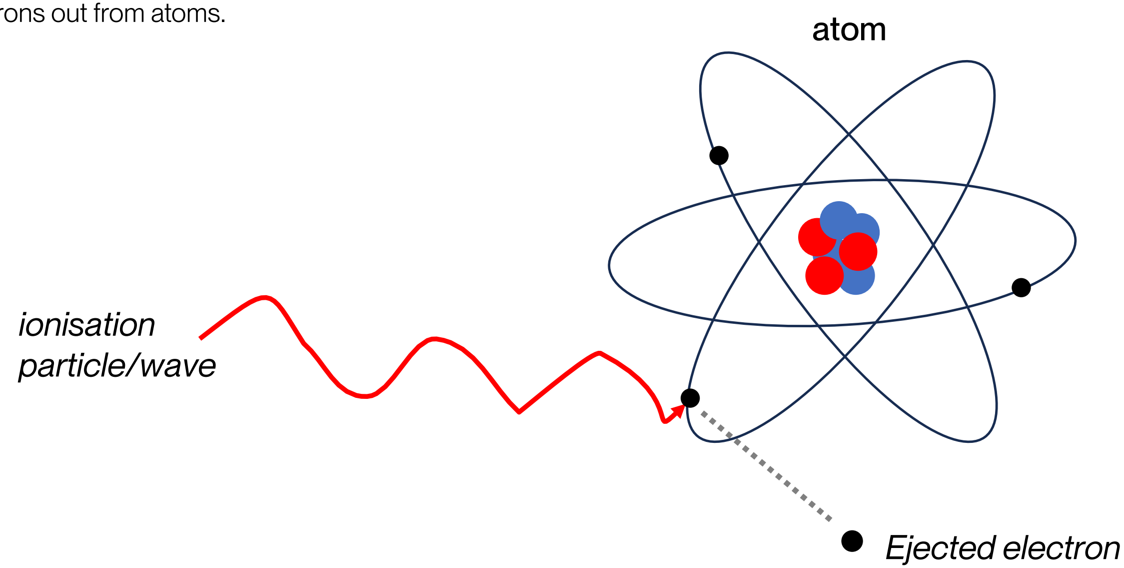


Spectrum of EMW. Image reproduced from https://commons.wikimedia.org/wiki/File:Electromagnetic-Spectrum.svg

CHAPTER OUTLINE:

/ Ionising Process

- The **ionising process** is the process by which electrically neutral atoms are transformed into electrically charged atoms or molecules (= **ions**) by losing or by gaining electrons.
- Radiation, e.g., X-rays and particles, is capable of tearing electrons out from atoms.
- During this process, the radiation loses its energy which it transmits to the matter. This energy, deposited by the electrons, will define the **radiation dose**.
  > see next pages



/ Types of Ionising Radiation

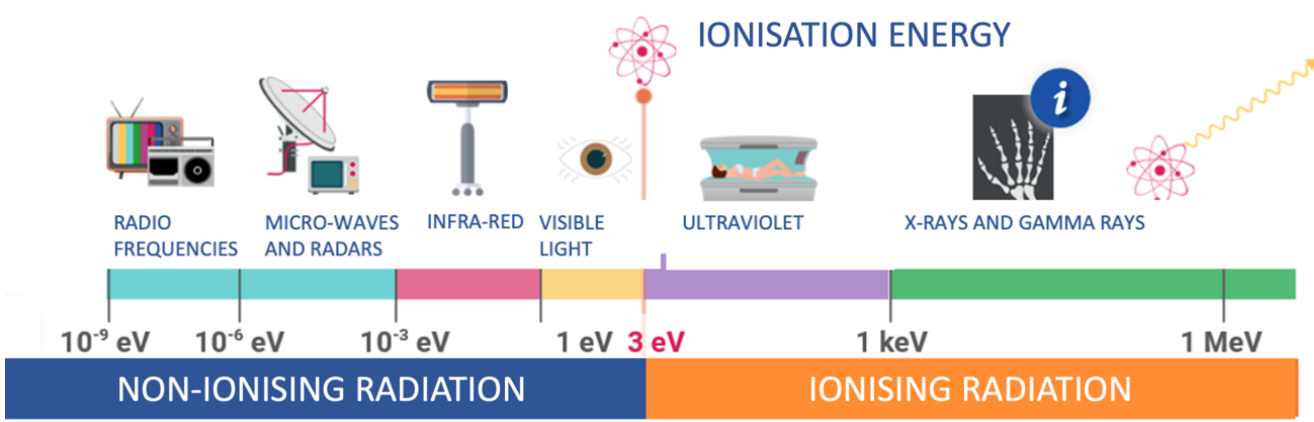
A key difference among EMW is their **ability to ionise atoms or molecules**. This ability depends on the **energy of the wave**, which increases with frequency.

Electromagnetic waves with **higher frequencies**, such as ultraviolet light, X-rays and gamma rays, have enough energy to ionise atoms and are called **ionising radiation**.

In contrast, waves with lower frequencies, such as radio waves, microwaves and visible light, do not have enough energy to cause ionisation and are considered **non-Ionising radiation**.

<!> ATTENTION

Electromagnetic waves (EMW) → only part of the spectrum is capable of ionisation!



Alpha radiation: occurs during the radioactive decay (alpha decay) of some radionuclides, e.g., uranium 238, radium 226, polonium 210 which give off **alpha particles** (= 2 protons + 2 neutrons, i.e., a doubly ionised helium atom). Alpha particles are slow and heavy, highly ionising (because of the double positive charge) and unable to travel very far (only a few cm in the air). They cannot penetrate the outer skin layers but can cause major cell damage if ingested in food or inhaled in air.

Beta radiation: occurs during the radioactive decay in which an atomic nucleus emits a beta particle. **Beta particles** (= high-energy, high-speed electrons or positrons) are less ionising and can travel farther (a few meters in the air) than alpha particles. They can penetrate the skin a few cm.

Gamma radiation: a **photon of energy** (no mass, EMW) is emitted from an unstable nucleus. Photons can travel much farther than alpha and beta particles

X-ray radiation: is produced by energy changes in an electron. **X-rays** (EMW) are produced in an X-ray tube. X-rays usually have lower energy than gamma radiation.

Neutron radiation: free neutrons are produced by nuclear fission, which occurs in neutron rich and proton poor nuclei. Neutrons travel thousands of meters through air. They do not ionise atoms directly but being absorbed in a stable atom, the atom becomes more unstable. The unstable atom then emits ionising radiation (**indirect ionisation**).

Particles capable of ionisation:

Penetrating power of different types of radiation

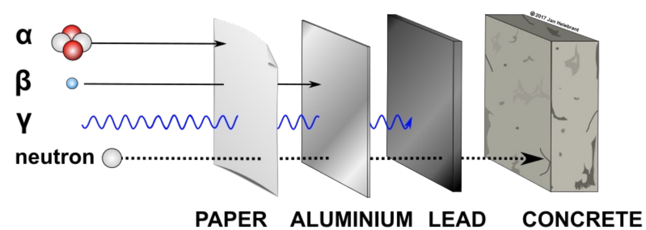


Image reproduced from: https://commons.wikimedia.org/wiki/File:Penetrating_power_of_different_types_of_radiation_-_alpha,_beta,_gamma_and_neutrons.svg

Principles of **Radiation Biology** and **Radiation Protection**

CHAPTER OUTLINE:

/ Dose Quantification

CHAPTER OUTLINE:

/ Absorbed Dose (D)

- The **absorbed dose (D)** is defined as the energy imparted by ionising radiation per unit mass of irradiated material.
- The absorbed dose is a measurable quantity.
- The absorbed dose can be measured for all types of ionising radiation.
- The unit of the absorbed dose is the Gray [Gy] → 1 Gy = 1 J/kg.
- The absorbed dose describes the energy deposited into a volume of tissue anywhere in the body. It is used to assess **the potential for biochemical changes** in tissues.

Measurable quantity

↓

$$D = \frac{Energy}{Mass} \quad \frac{[J]}{[kg]}$$

/ Equivalent Dose (H)

- Not all types of radiation cause the same biological damage.
- The radiation weighting factor W_R is the factor reflecting the relative effectiveness of the type of radiation in producing biological damage.
- The product of the absorbed dose by the radiation weighting factor W_R is called the **equivalent dose H**.
- The unit of the equivalent dose is the Sievert [Sv] → 1 Sv = 1 J/kg.
- H takes the **damaging properties of different types of radiation** into account.

$$H = D * W_R \frac{[J]}{[kg]}$$

TYPE OF RADIATION	RADIATION WEIGHTING FACTOR W_R
X-rays, gamma rays, beta particles	1
Protons	2
Neutrons*	2.5-20
Alpha particles and multiple charged particles	20

*w_R of neutrons is a continuous function of energy

/ Effective Dose (E)

/ Not all tissues are equally sensitive to radiation.

/ The tissue weighting factor W_T reflects the proportion of the detriment from stochastic effects resulting from irradiation of that tissue compared to uniform whole-body irradiation.

/ The W_T were developed for a reference population of equal numbers of both genders and a wide range of ages.

/ The effective dose (E) is the sum of the product of the equivalent dose to each organ multiplied with its weighting factor.

/ The unit of the effective dose is the Sievert [Sv].

/ E takes the radiosensitivity of different tissues into consideration.

$$E = \sum_T [W_T * H]$$

ORGAN/TISSUE	W_T
Breast, Bone marrow, colon, lung, stomach, remainder*	0.12
Gonads	0.08
Bladder, oesophagus, liver, thyroid	0.04
Bone surface, brain, salivary gland, skin	0.01
TOTAL	1

*shared by remainder tissues are adrenals, extrathoracic tissue, gallbladder, heart, kidneys, lymphatic nodes, muscle, oral mucosa, pancreas, prostate (male), small intestine, spleen, thymus, uterus/cervix (female)

Absorbed Dose, Equivalent Dose and Effective Dose

<!> ATTENTION

Absorbed Dose D [Gy] → W_R (Radiation weighting factor) → **Equivalent Dose H [Sv]** → W_T (Tissue/organ weighting factor) → **Effective Dose E [Sv]**

The absorbed dose is the energy absorbed per unit of mass.

The unit is the Gy.

The equivalent dose is the product of the absorbed dose multiplied with the radiation weighting factor.

The unit is the Sv.

The effective dose is the sum of the product of the equivalent dose to each organ multiplied with its weighting factor.

The unit is the Sv.

CHAPTER OUTLINE:

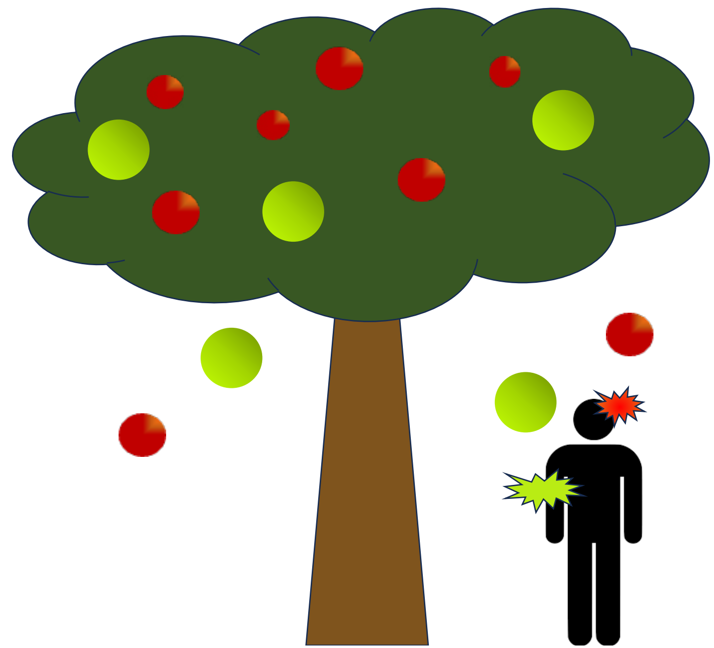
<!> ATTENTION

Analogy using an apple tree

The energy deposited by the apple falling on the man is measured in Gray > **Absorbed dose (D)**.

The different types of apples (green or red) have different effectiveness in producing biological damage, expressed in Sievert > **Equivalent dose (H)**.

The effects are different depending on the location of the impact of the apple on the person's body. The radiosensitivity of the irradiated area is considered and expressed in Sievert > **Effective dose (E)**.



Effects on the Human Body

CHAPTER OUTLINE:

/ Interactions of Ionising Radiation With the Cell

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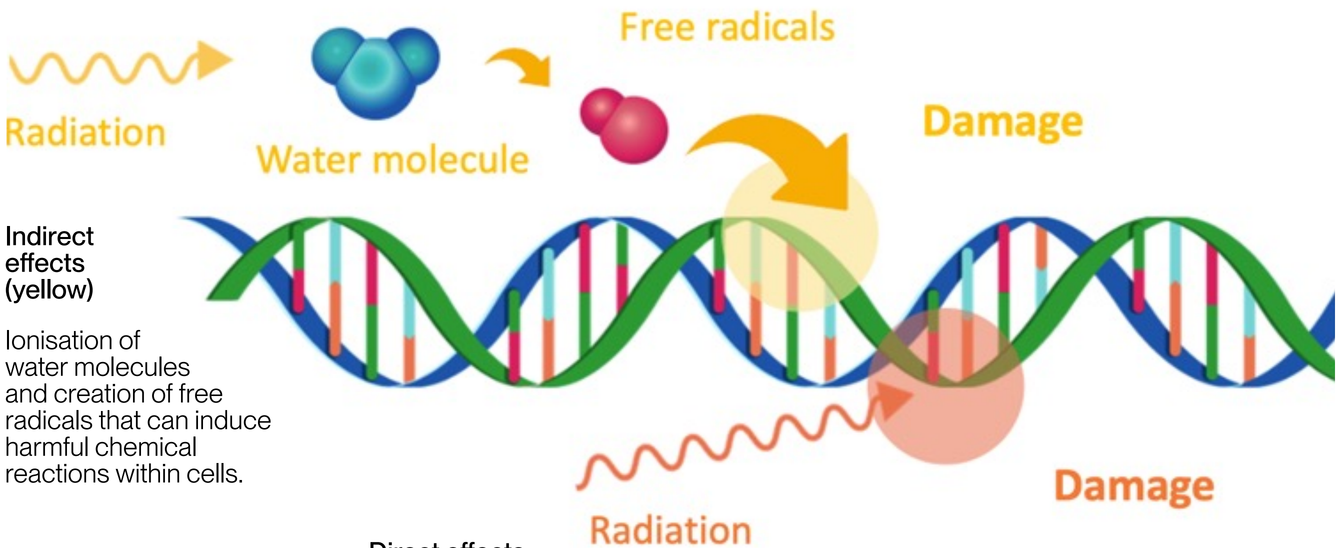


Indirect effects (yellow)

Ionisation of water molecules and creation of free radicals that can induce harmful chemical reactions within cells.

Direct effects (orange)

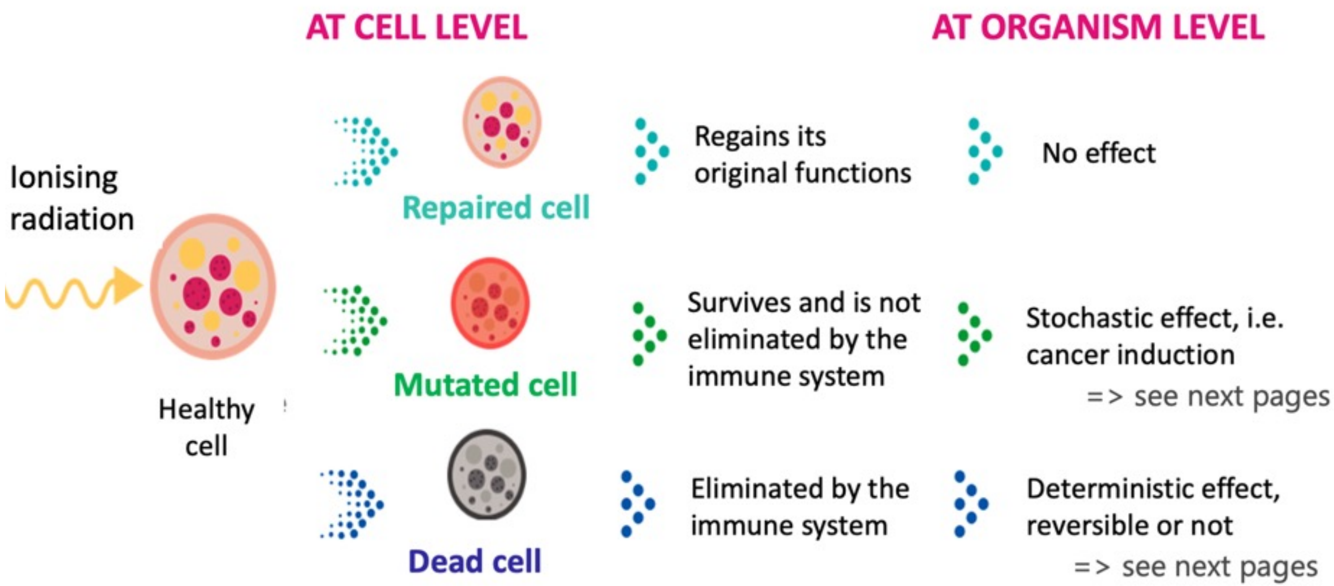
Ionisation of atoms in the DNA molecule creating ions capable of damaging it.

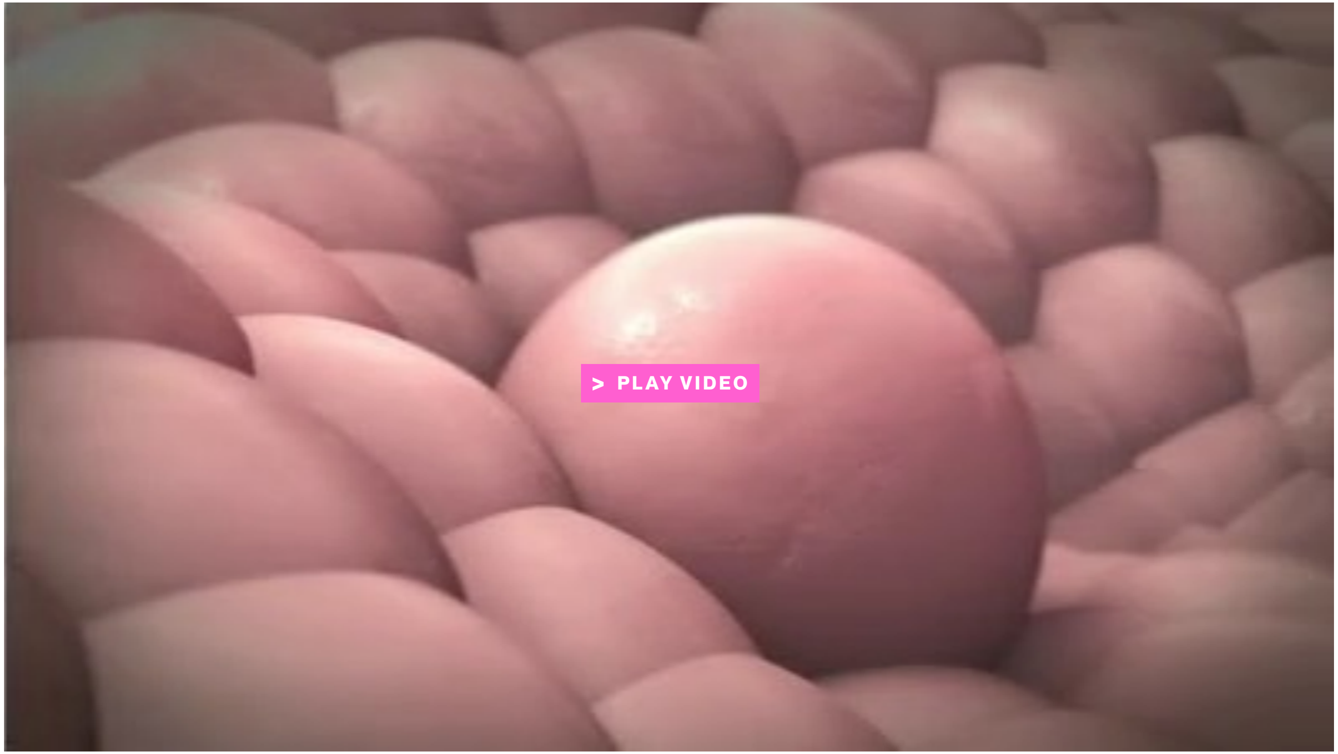
CHAPTER OUTLINE:

/ Effects of Radiation Exposure

<!> ATTENTION

DNA damage can lead to one of the following effects:





CHAPTER OUTLINE:

Source: CDC Centers for Disease Control and Prevention
CDC 24/7: Saving Lives, Protecting People™

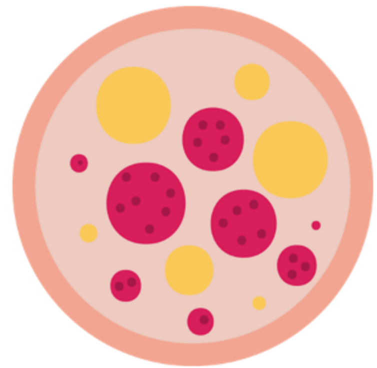
<!> ATTENTION

A cell is more sensitive to radiation when:

- It is young
- It is poorly differentiated
- It has a fast turnover rate

This is why children are more sensitive to radiation than older people.

Reasons why some tissues are more sensitive than others.



The **law of Bergonie and Tribondeau** states that the radiosensitivity of a biological tissue is directly proportional to its mitotic activity and inversely proportional to the degree of differentiation of its cells. In other words, a high proliferation rate of cells and a high growth rate for tissues result in increased radiosensitivity.

/ Characteristics of Radiation Effects

<!! ATTENTION

Radiation effects on biological systems vary depending on the type of radiation, dose, duration of exposure and the biological system exposed.

Radiation effects can be categorised as **stochastic (by chance) versus deterministic, acute versus chronic, direct versus indirect, systemic versus localised**.

>|< COMPARE

	DETERMINISTIC versus	STOCHASTIC
DOSE LEVEL	« High » doses	Already at low doses
THRESHOLD	Threshold demonstrated (General value: 0,5 Gy)	No threshold demonstrated
MECHANISMS	Cellular destruction: loss of functionality of a tissue/organ	Cellular modification: induction of cancer, other somatic diseases
DELAYS	Short	Latency up to several years
VARIATION WITH DOSE	Severity	Probability of dying from cancer ↗ 5% / Sv

CHAPTER OUTLINE:

>|< COMPARE

<!> ATTENTION

Acute versus chronic effects

- Acute effects result from a high dose of radiation over a short period, often leading to immediate symptoms. These can include radiation burns, acute radiation syndrome (ARS), and tissue damage.
- Chronic effects result from long-term, low-level exposure, often manifesting years after exposure. Chronic effects can include cancer, cardiovascular disease and cataracts.

Direct versus indirect effects > see page 21

- Direct Effects: radiation directly ionises atoms in the DNA leading to mutations and cell death.
- Indirect Effects: radiation ionises water molecules within the body producing free radicals that can damage DNA and other cellular structures.

Systemic versus localised effects

- Systemic Effects occur when radiation affects the entire body, such as radiation sickness.
- Localised Effects occur when only a specific area of the body is exposed to radiation, such as localised tissue damage or burns.

Cumulative effects

- Repeated exposures increase the risk and severity of effects. The body has some capacity to repair radiation damage, but repeated exposures can overwhelm these mechanisms.

CHAPTER OUTLINE:

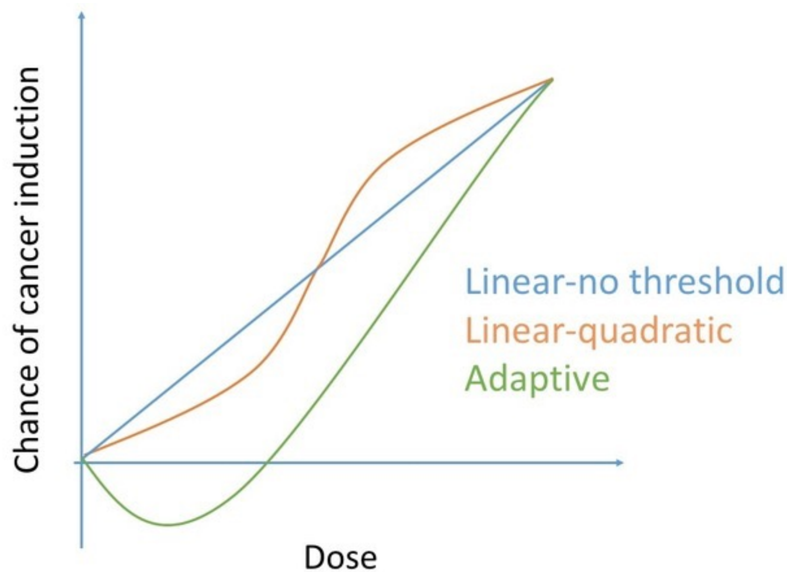
/ Stochastic Effects – The Linear Non-Threshold Model

<!> ATTENTION

There are **different models** used in radiation protection to estimate the **stochastic health effects of ionising radiation.**

The most accepted model is the **Linear Non-Threshold (LNT) model.**

The LNT is used by regulatory bodies for formulating health policies.



The different models used in radiation protection to estimate stochastic effects of radiation.
Source: https://radiopaedia.org/articles/5099

CHAPTER OUTLINE:

/ Stochastic Effects - Lifetime Attributable Risk (LAR)

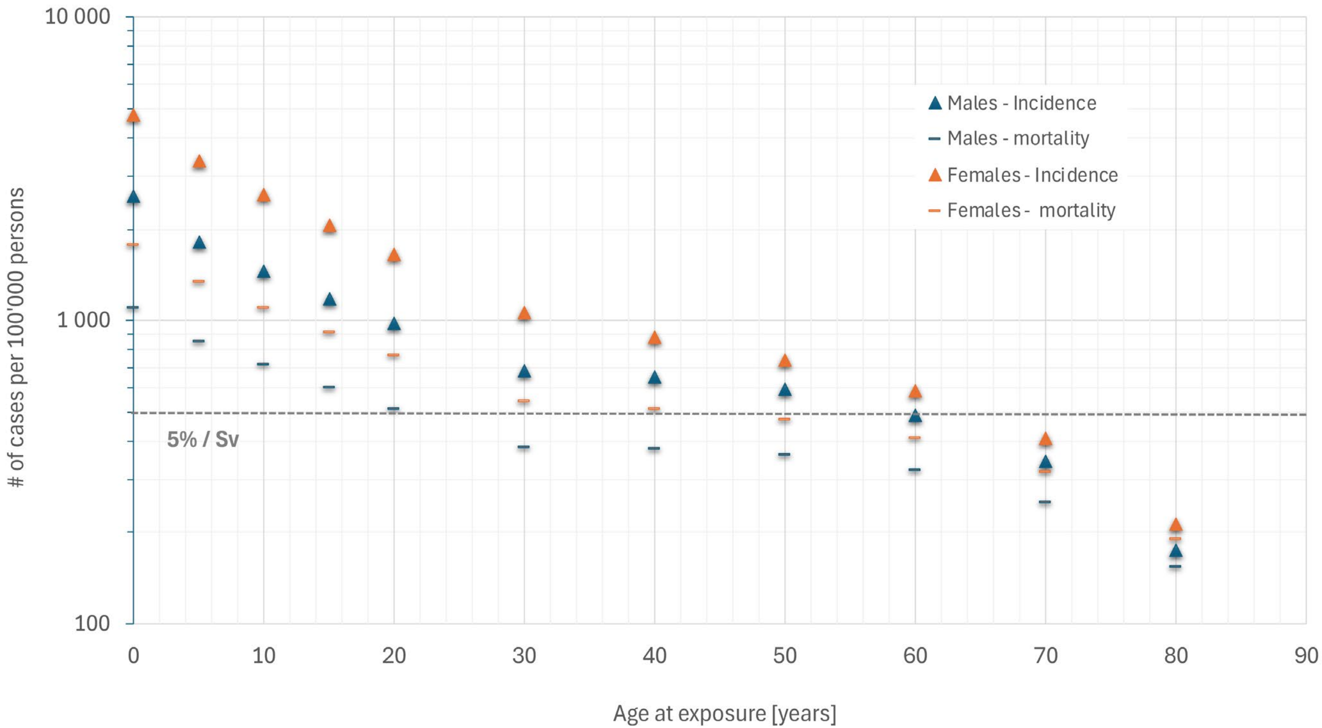
Lifetime Attributable Risk (LAR) = probability that an individual will develop a particular disease, typically cancer, because of exposure to a hazardous agent like radiation over their lifetime. It represents the **additional risk above the baseline risk** (the risk of developing the disease without any exposure to the hazardous agent).

The **key characteristics of LAR related to radiation** include:

- its cumulative nature, reflecting the risk of disease from lifetime radiation exposure
- it is a population-based metric, derived from studies like those on atomic bomb survivors
- it varies by age and sex, and is most often calculated for cancer, though applicable to other diseases
- it follows a dose-response relationship, with risk increasing with radiation dose
- is typically expressed as a probability

LAR is crucial in risk assessments for **long-term health impacts from radiation** in various contexts and informs guidelines set by regulatory bodies like the Environmental Protection Agency (EPA) and the International Commission on Radiation Protection ICRP.

Example calculation: if 100,000 people exposed to radiation develop 500 additional cancer cases: LAR for cancer = 0.5%.



Lifetime Attributable Risk (LAR) of solid cancer incidence/mortality, for a single dose of 0.1 Gy.
Source : The data has been extracted from Tables 12D-1 and 12D-2, of the publication: Health Risks from Exposure to Low Levels of Ionising Radiation: BEIR VII – Phase 2.

CHAPTER OUTLINE:

/ Deterministic Effects

<!:> ATTENTION

- Deterministic effects have a **threshold** below which the effect does not occur.
- When the effect appears, its **severity depends on the radiation dose**.

Examples of deterministic effects and onset of appearance

EFFECT	DOSE THRESHOLD [GY]	ONSET
Cataract	0.5	Several years
Skin erythema	2-6	Hours/weeks
Sterility	4-6 (male) 4-20 (female)	3 weeks < 1 week
Hair loss	7	3 weeks
Irreversible skin damage	18	> 10 weeks
Lethality (whole body irradiation)	3-5	30-60 days

CHAPTER OUTLINE:

/ In Utero Exposure

>|< COMPARE

As for adults, for **in utero exposure**, there are two types of possible effects due to ionising radiation:

Deterministic effects :

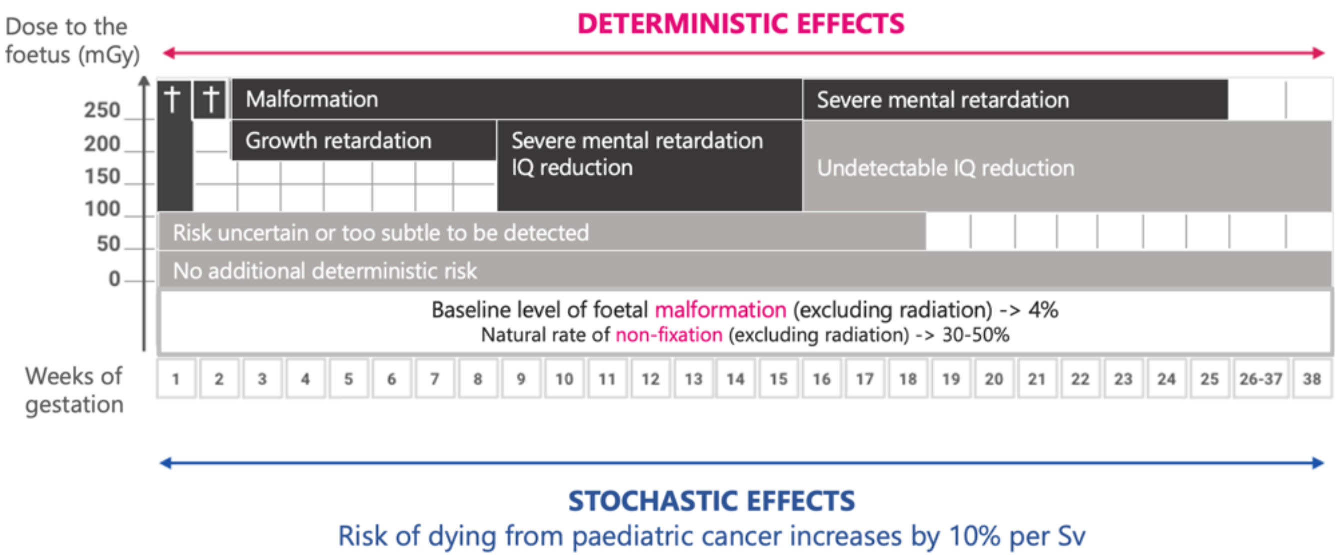
- The effects appear above a threshold of 100 mGy.
- The effects depend on the stage of pregnancy: different damaged organs (malformation, IQ reduction).
- The effects increase with increasing dose.

Stochastic effects :

- The stochastic risk is present from the implantation moment until the end of pregnancy.
- The probability of occurrence is higher for the foetus (10 to 20% per Sv) compared to adults (5% per Sv).

/ In Utero Exposure

The effects depend on the **gestational age**:



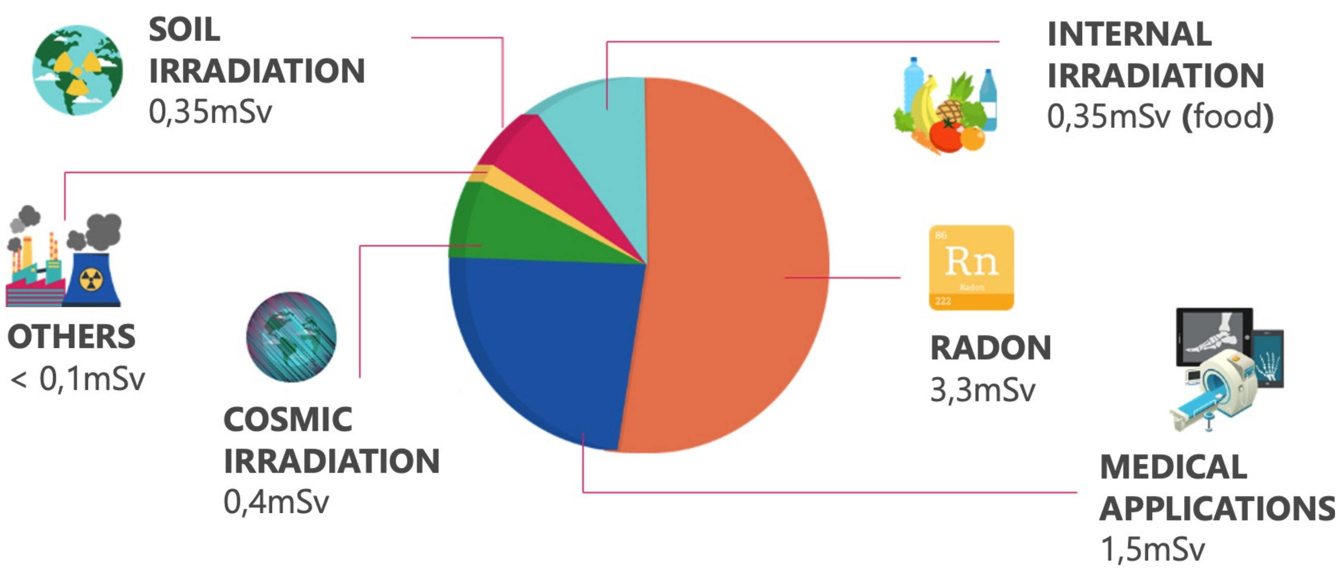
Sources of Exposure and Order of Magnitude

CHAPTER OUTLINE:

Sources of Radiation Exposure

Every day, humans are exposed to radioactivity, whether of natural or artificial origin.

The exposure varies from person to person, depending on location and lifestyle.



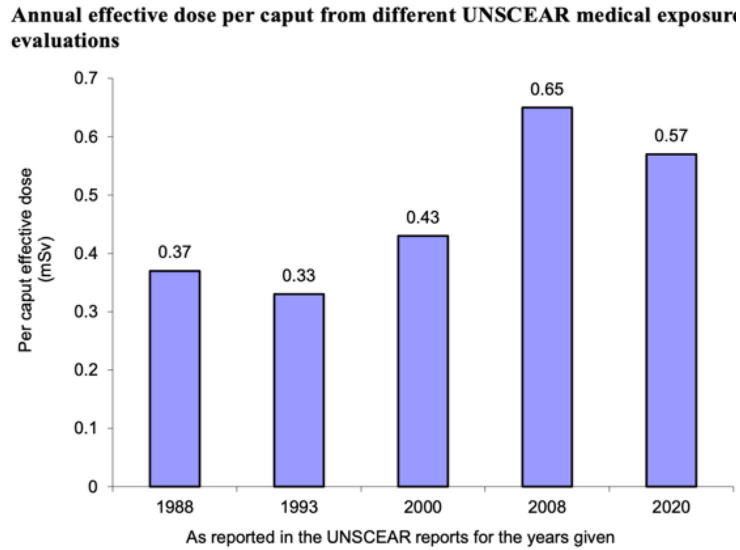
The numbers in this figure are shown for the Swiss population. The average annual effective dose per person in the Swiss population is 6 mSv. Source: The data has been extracted from BAG report 2022 (rounded values).

CHAPTER OUTLINE:

Global Medical Radiation Exposure

Medical exposure is the **largest human-made source** of radiation exposure globally.

- Approximately 4.2 billion medical radiological examinations were conducted in 2020 for a global population of 7.3 billion, contributing to a significant collective radiation dose.
- The global population received an **effective dose per capita of 0.57 mSv** from these medical procedures in 2020, excluding radiotherapy.
- There is a high degree of **uncertainty** (±30%) in these estimates due to data gaps and variations in dose per examination across different regions. The data **do not take** occupational radiation exposure into account.

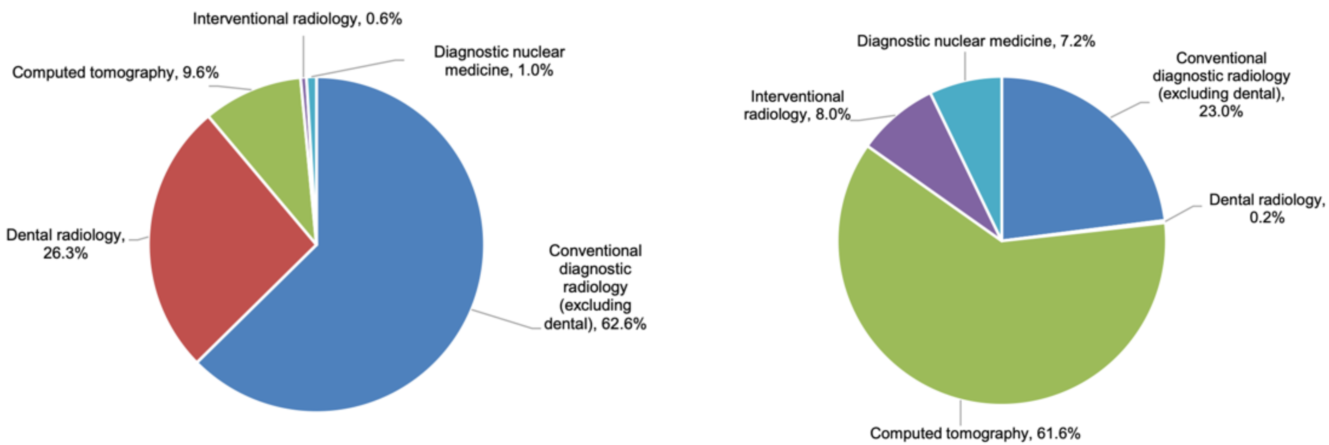


Source: UNSCEAR report 2020/2021 – Volume 1 Scientific Annex A. https://www.unscear.org/unscear/uploads/documents/unscear-reports/UNSCEAR_2020_21_Report_Vol.I.pdf

Medical procedures and dose per imaging modality (excluding radiotherapy)

(a) Examinations/procedures

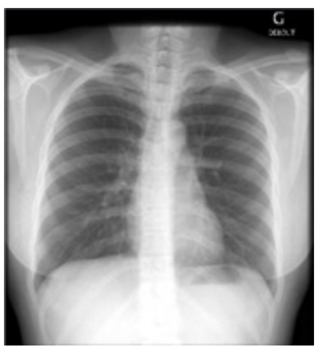
(b) Collective effective dose

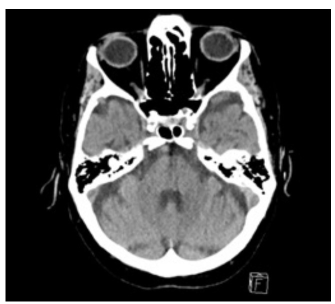


Distribution of examination/procedures by imaging modality (a) and their **contributions to the collective effective dose** from medical exposures excluding radiotherapy (b).
Source: UNSCEAR report 2020/2021 – Volume 1 Scientific Annex A.
https://www.unscear.org/unscear/uploads/documents/unscear-reports/UNSCEAR_2020_21_Report_Vol.I.pdf

CHAPTER OUTLINE:

Examples of Effective Radiation Doses for Different Imaging Modalities in Adults





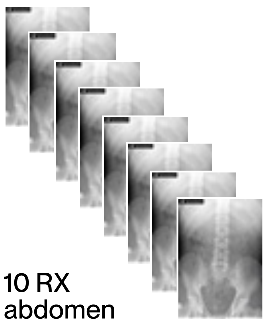
TYPE OF RADIOLOGICAL EXAMINATION	EFFECTIVE DOSE (mSv)	CORRESPONDS TO NATURAL IRRADIATION DURING
X-ray of the extremities (hand, foot)	0.001	2 hours
Dental X-ray	< 0.01	< 1 day
Chest X-ray	0.05	4 days
Head X-ray	0.05	4 days
Mammography (4 acquisitions)	0.1	8 days
Abdominal X-ray	0.7	2 months
Pelvic X-ray	1	3 months
Head CT scan	2	6 months
Chest CT scan	3.5	1 year
Abdominal CT scan	8	2 years

Principles of **Radiation Biology** and **Radiation Protection**

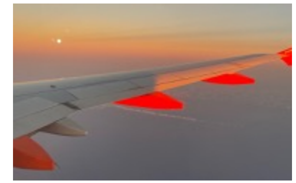
CHAPTER OUTLINE:

/ Order of Magnitude

1 CT abdomen ≈ 8 mSv (1 acquisition)

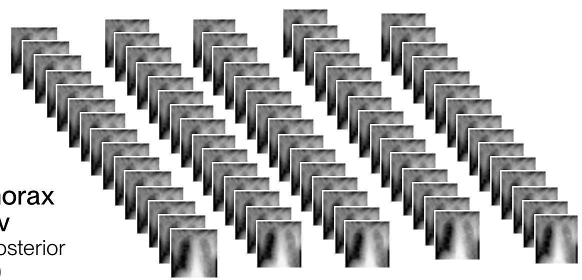


10 RX abdomen ≈ 0.8 mSv



≈ 100 flights GVA ⇄ JFK

GENEVA > NEW YORK Dose received from the flight = 0.0432 mSv
Time of flight = 9 h



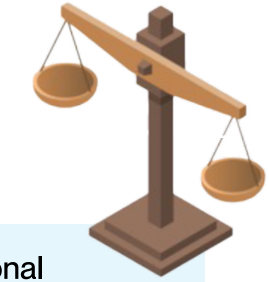
80 RX thorax ≈ 0.1 mSv (anterior-posterior and profile)

CHAPTER OUTLINE:

Radiation Protection Principles

CHAPTER OUTLINE:

/ Scientific Background, Doctrine, Standards and Legislation



International scientific studies:

a scientific consensus is developed at the international level from studies carried out in different countries > i.e., UNSCEAR*.

General principles, doctrine:

based on scientific, economic and social considerations, the International Commission on Radiological Protection (ICRP) proposes a method of managing radiological risk.

Pre-regulatory standards:

International governmental agencies (IAEA**, Euratom***) develop standards intended for states, which are more or less legally binding.

National legislation:

National regulations aim to protect workers, members of the public and patients exposed to Ionising radiation.

* The **United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)**, established in 1955, collects and analyses data from various sources, conducts scientific studies on the biological impacts of radiation and evaluates associated health risks. It provides scientific advice to the United Nations (UN), guiding international radiation protection standards. It publishes comprehensive reports used by governments and researchers worldwide and collaborates with organisations like the IAEA and the WHO to ensure global standards are informed by the best scientific evidence.

** The **International Atomic Energy Agency (IAEA)**, established in 1957, promotes peaceful nuclear energy use and prevents nuclear weapons proliferation. As an independent UN agency, it assists countries in utilising nuclear energy for electricity, medicine and agriculture, while ensuring safety and security through international standards. The IAEA implements safeguards to verify non-proliferation, supports scientific research and provides training. It collaborates internationally to advance safe nuclear technology use for global development and health.

*** **Euratom**, established in 1957, is the European Atomic Energy Community focused on coordinating and promoting the peaceful use of nuclear energy among EU member states. Its key functions include ensuring nuclear safety, supporting research and development, safeguarding nuclear materials, regulating nuclear fuel supply and representing members in international agreements. Operating under its own legal framework, Euratom remains vital for nuclear safety, research and regulation within the EU, despite the shift towards sustainable energy policies.

/ Principles of **Radiation Biology** and **Radiation Protection**

CHAPTER OUTLINE:

Council Directive 2013/59/Euratom, December 5th 2013

<!> ATTENTION

CHAPTER III

SYSTEM OF RADIATION PROTECTION

Article 5

General principles of radiation protection

USTIFICATION

PTIMISATION

IMITATION

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Contents

II *Non-legislative acts*

DIRECTIVES

★ Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom 1

Source: https://osha.europa.eu/en/legislation/directives/directive-2013-59-euratom-protection-against-ionising-radiation

/ Justification

<!> ATTENTION

An activity is justified

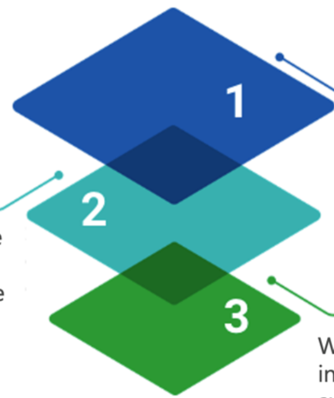
- when the **benefits** associated with it **clearly outweigh the harms** due to radiation
- when there is **no alternative** that is generally more favourable for humans and the environment

This principle can be summarised by the phrase: ***"Do more good than harm"***

EXAMPLES:

- Reducing a fracture using a fluoroscopy device.
- Making a diagnosis with a CT scanner.

Justification - Three Levels of Justification in Medicine



FUNDAMENTAL JUSTIFICATION

The society considers that the use of ionising radiation is justified when it allows a diagnosis to be made or a pathology to be treated.

JUSTIFICATION OF DIAGNOSTIC OR THERAPEUTIC PROCEDURES

The widespread application of a procedure must be justified → no other existing procedure with less radiation is as effective (recommendations of scientific societies).

JUSTIFICATION OF INDIVIDUAL APPLICATIONS

When a physician prescribes or performs examinations involving ionising radiation, he/she must consider the available diagnostic information and the patient's medical history → to avoid unnecessary exposure.

Doctors **prescribing** radiation procedures and doctors who **perform** them are responsible for applying the principle of justification.

CHAPTER OUTLINE:

<∎> ATTENTION

Optimisation

The optimisation principle is also called the **ALARA** principle :

As
Low
As
Reasonably
Achievable

- An optimum in the benefit/risk ratio must be found.
- Economic and social aspects must also be considered.

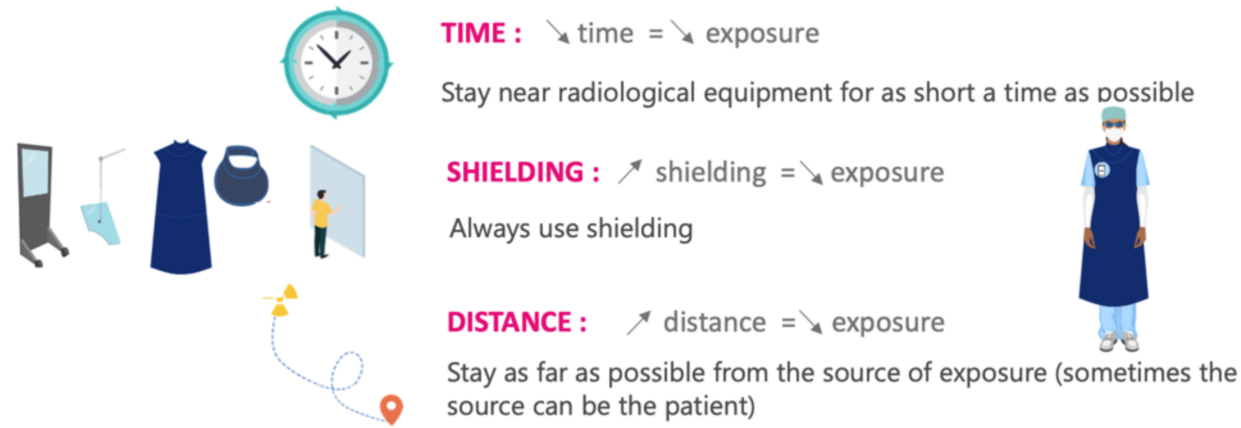
This involves optimising procedures, using protective measures and continually striving to minimise exposure. Radiation exposure should be limited to levels below the prescribed dose limits set by regulatory bodies.

CHAPTER OUTLINE:

Optimisation – Occupational

<:> ATTENTION

There are **3 fundamental rules in radiation protection for professionally exposed staff:**



Further radiation protection measures include:

- **continuous monitoring** of radiation levels in the workplace
- use of **personal dosimeters** to track individual exposure and regular health surveillance of personnel exposed to radiation
- **adequate training** about radiation risks, safety procedures and the proper use of protective equipment and ongoing education regarding the **best practices and changes in regulations or technology**

CHAPTER OUTLINE:

/ Optimisation - Patients

<!> ATTENTION

Non-exhaustive list of actions for radiation exposure optimisation in patients:

- Minimise the number of acquisitions/ projections/images.
- Collimation.
- Appropriate patient positioning (PA vs AP, centring, etc.).
- Protocol optimisation.
- Implementation of modern dose reduction technologies such as automatic exposure control and organ-based tube current modulation.
- Selective filtration, appropriate exposure parameters.
- Iterative reconstruction.
- Establishing and monitoring of Diagnostic Reference Levels (DRLs)*.
- Communication with patients to encourage their cooperation.

CHAPTER OUTLINE:

* see next page

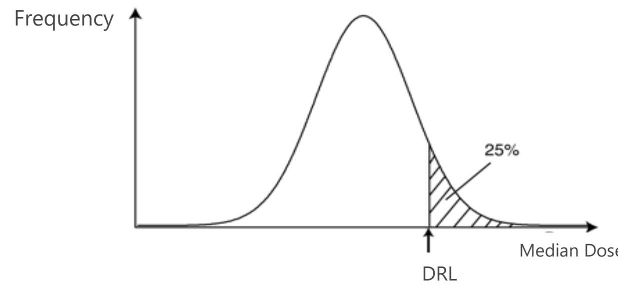
Diagnostic Reference Levels (DRL) are an essential part of ensuring patient safety in medical imaging. They help prevent unnecessary radiation exposure by providing a benchmark for the typical dose used in common diagnostic procedures, encouraging continuous optimisation of imaging practices.

DRLs **are**:

- generic for a collective of patients
- modality specific
- anatomical region specific

DRLs **are not**:

- a limit between good and bad practice
- a dose limit
- intended to be applied to individual patients and individual examinations



- **National DRLs (NDRLs)** are setup via a national survey by adopting the **third quartile value** of the distribution of the median doses.
- **Local DRLs (LDRLs)** correspond to the local practice of an institution/group of institutions by adopting the third quartile value of the median doses; each imaging centre should establish its own **LDRLs** or "**Diagnostic Standard Doses – DSDs**".
- A **comparison** of DSDs to NDRLs should be performed and possible corrective measures implemented.
- In case of exceeding NDRLs, an analysis should be performed.
- The revision of DRLs (NDRLs and LDRLs) is an iterative process.

Currently there is a **consensus view** of the main bodies involved in radiation safety and imaging.

Gonad and Patients Shielding Group (GAPS): European Consensus

EUROPEAN SOCIETY OF RADIOLOGY

EFOMP EUROPEAN FEDERATION OF ORGANISATIONS FOR MEDICAL PHYSICS

EURADOS

ESPR European Society of Paediatric Radiology

EUROSAFE IMAGING

EFRS EUROPEAN FEDERATION OF RADIOGRAPHER SOCIETIES

EUROPEAN ACADEMY DENTOMAXILLOFACIAL RADIOLOGY

Their work and recommendations have been published in different scientific journals for better accessibility.

<·∞> REFERENCE

Hiles P, Gilligan P, Damilakis J, Briers E, Candela-Juan C, Faj D, Foley S, Frija G, Granata C, de Las Heras Gala H, Pauwels R, Sans Merce M, Simantirakis G, Vano E. European consensus on patient contact shielding. Insights Imaging. 2021 Dec 23;12(1):194. doi: 10.1186/s13244-021-01085-4. PMID: 34939154; PMCID: PMC8695402.

<!> ATTENTION

This is the outcome of the consensus on patient contact shielding:

Table 1 Rationale for consensus statements

Rationale	Consensus Recommendation	Symbol
Evidence that using patient contact shielding is beneficial and effective	'Should use shielding'	
General agreement favours usefulness of patient contact shielding in some circumstances	'May use shielding'	
Evidence or general agreement not to use patient contact shielding	'Not recommended to use shielding'	

<∞> REFERENCE

Table reproduced from: Hiles P, Gilligan P, Damilakis J, Briers E, Candela-Juan C, Faj D, Foley S, Frija G, Granata C, de Las Heras Gala H, Pauwels R, Sans Merce M, Simantirakis G, Vano E. European consensus on patient contact shielding. Insights Imaging. 2021 Dec 23;12(1):194. doi: 10.1186/s13244-021-01085-4. PMID: 34939154; PMCID: PMC8695402.

CHAPTER OUTLINE:

This is the outcome of the consensus on patient contact shielding:

<!> ATTENTION

Patient shielding is **generally not recommended** for most imaging modalities, buy may be used in some specific situations.

Application	Imaging modality	Inside or outside FOV	Recommendation	Symbol
Thyroid contact shielding	Radiography, Mammography, Fluoroscopy, CT	Outside	'Not recommended to use shielding'	
Thyroid contact shielding	Dental intraoral and cephalometric radiography	Outside	'May use shielding'	
Thyroid contact shielding	CBCT	Outside	'May use shielding'	
Thyroid contact shielding	All X-ray (except Ceph.)	Inside	'Not recommended to use shielding'	
Thyroid contact shielding	Cephalometric radiography	Inside	'May use shielding'	

Application	Imaging modality	Inside or outside FOV	Recommendation	Symbol
Embryo / Fetal contact shielding	All X-ray	Inside	'Not recommended to use shielding'	
Embryo / Fetal contact shielding	Radiography, Mammography, Fluoroscopy, Dental Radiography, CT	Outside	'Not recommended to use shielding'	

Application	Imaging modality	Inside or outside FOV	Recommendation	Symbol
Breast contact shielding	All X-ray	Both	'Not recommended to use shielding'	

Application	Imaging modality	Inside or outside FOV	Recommendation	Symbol
Eye lens contact shielding	All X-ray	Both	'Not recommended to use shielding'	

Application	Imaging modality	Inside or outside FOV	Recommendation	Symbol
Male and female gonad contact shielding	All X-ray	Both	'Not recommended to use shielding'	

<∞> REFERENCE

Table reproduced from: Hiles P, Gilligan P, Damilakis J, Briers E, Candela-Juan C, Faj D, Foley S, Frija G, Granata C, de Las Heras Gala H, Pauwels R, Sans Merce M, Simantirakis G, Vano E. European consensus on patient contact shielding. Insights Imaging. 2021 Dec 23;12(1):194. doi: 10.1186/s13244-021-01085-4. PMID: 34939154; PMCID: PMC8695402.

CHAPTER OUTLINE:

/ Limitation

<!> ATTENTION

The **limitation principle** consists of establishing **limit dose values**, indicated in the national legislation. Three categories of exposed persons have been defined:

Professionally exposed worker

20 mSv/year whole body
20 mSv/year eye lens
500 mSv/year for the extremities

Publlic + professionally exposed pregnant women

1 mSv/year

Patient

No dose limit
The principle of justification applies.

CHAPTER OUTLINE:

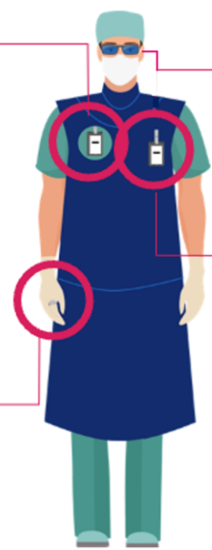
/ Limitation – Professionally Exposed Personnel

<!> ATTENTION

Professionally exposed workers are required to wear different dosimeters depending on the type of work performed.

The whole-body dosimeter is placed at the chest level (or at the abdominal level for pregnant workers) under the apron. Used to estimate the **effective dose**.

The dosimeter placed at the eyes level provides an estimation the **dose to the eye lens**.



The over apron dosimeter provides an estimation of the **dose for the organs placed outside the apron**. It can also be used, depending on the local legislation, to estimate **more accurately** the effective dose or even the dose to the eye lens.

The extremity dosimeter is placed on the finger to estimates the **dose to the hands**. Normally required when performing interventional procedures or activities with open sources (i.e. Nuclear Medicine). Used to estimate the extremity dose.

CHAPTER OUTLINE:

/ Take-Home Messages

<!> ATTENTION

- There are different types of ionising radiation.
- Absorbed dose (D) is defined as the energy imparted by ionising radiation per unit mass of irradiated material, it is the only measurable quantity.
- The equivalent dose (H) is the product of the absorbed dose multiplied with the radiation weighting factor.
- The effective dose (E) is the sum of the product of the equivalent dose to each organ multiplied with its weighting factor.
- Radiation can damage the cell directly or indirectly.
- There are two characteristic effects of ionising radiation: deterministic and stochastic.
- The linear non threshold model is the most accepted model to estimate the stochastic health effects of ionising radiation.
- We are all exposed to natural radiation.
- Physicians prescribing irradiating procedures and physicians who perform them are responsible for applying the principle of justification.
- Optimisation is achieved following the ALARA (As Low As Reasonably Achievable) principle.
- There are dose limits for occupationally exposed workers and the public but not for the patient. For the patient, the justification and optimisation principles apply.

CHAPTER OUTLINE:

/ References

/ 1. Health Risks from Exposure to Low Levels of Ionising Radiation: BEIR VII – Phase 2. 2006. https://nap.nationalacademies.org/catalog/11340/health-risks-from-exposure-to-low-levels-of-Ion-ising-radiation

/ 2. Radioprotection et surveillance de la radioactivité en Suisse – Résultats 2022. May 2023.

/ 3. ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4).

/ 4. ICRP, 2000. Pregnancy and Medical Radiation. ICRP Publication 84. Ann. ICRP 30 (1).

/ 5. ICRP, 2017. Diagnostic reference levels in medical imaging. ICRP Publication 135. Ann. ICRP 46(1).

/ 6. European consensus on patient contact shielding. Peter Hiles, Patrick Gilligan, Shane Foley, Guy Frija, Claudio Granata, Hugo de las Heras Gala, Ruben Pauwels, Marta Sans Merce , Georgios Simantirakis, Eliseo Vano. Insights into Imaging 12 (2021) 194 / Physica Medica 96 (2022) 198 / Radiography 28 (2022) 353.
https://doi.org/10.1186/s13244-021-01085-4
https://doi.org/10.1016/j.ejmp.2021.12.006
https://doi.org/10.1016/j.radi.2021.12.003

CHAPTER OUTLINE:

/ Test Your Knowledge

/ Test Your Knowledge

<?> QUESTION

1

Once irradiated, a cell's DNA can (several answers possible):

- ☐ Not repair itself and cause the cell to die.
- ☐ Repair all the damage without any after-effects.
- ☐ Repair itself by making mistakes (mutation).

/ Test Your Knowledge

<?> ANSWER

1 Once irradiated, a cell's DNA can (several answers possible):

- Not repair itself and cause the cell to die.
- Repair all the damage without any after-effects.
- Repair itself by making mistakes (mutation).

/ Test Your Knowledge

<?> QUESTION

2 The general threshold for the appearance of deterministic effects is:

- ☐ 0.5 Gy
- ☐ 20 mSv
- ☐ No threshold

/ Test Your Knowledge

<?> ANSWER

2 The general threshold for the appearance of deterministic effects is:

- ■ 0.5 Gy
- ☐ 20 mSv
- ☐ No threshold

/ Test Your Knowledge

<?> QUESTION

3 Stochastic effects represent (several answers possible):

- ☐ An increase in the risk of cancer occurrence of 10 to 20% per Sievert in the foetus.
- ☐ An increase in the risk of cancer occurrence of 5% per Sievert in adults.
- ☐ The occurrence of tissue effects as soon as a threshold dose is exceeded.

/ Test Your Knowledge

<?> ANSWER

3 Stochastic effects represent (several answers possible):

- ■ An increase in the risk of cancer occurrence of 10 to 20% per Sievert in the foetus.
- ■ An increase in the risk of cancer occurrence of 5% per Sievert in adults.
- ☐ The occurrence of tissue effects as soon as a threshold dose is exceeded.

/ Test Your Knowledge

<?> QUESTION

4 A single 2 Gy irradiation to the skin can cause in the short term:

- ☐ No reaction.
- ☐ Tissue necrosis.
- ☐ Transient erythema.

/ Test Your Knowledge

<?> ANSWER

4 A single 2 Gy irradiation to the skin can cause in the short term:

- ☐ No reaction.
- ☐ Tissue necrosis.
- ■ Transient erythema.

/ Test Your Knowledge

<?> QUESTION

5 The fundamental principles of radiation protection are:

- ☐ Time, shielding, distance.
- ☐ Justification, optimisation and limitation.
- ☐ Justification, optimisation, limitation and training.

/ Test Your Knowledge

<?> ANSWER

5 The fundamental principles of radiation protection are:

- ☐ Time, shielding, distance.
- ■ Justification, optimisation and limitation.
- ☐ Justification, optimisation, limitation and training.

/ Test Your Knowledge

<?> QUESTION

6 Diagnostic Reference Levels:

- ☐ They represent the limit to patient dose.
- ☐ Are independent of the anatomical region.
- ☐ Are a tool for optimisation of patient dose.
- ☐ If exceeded for a patient, it indicates bad practice.

/ Test Your Knowledge

<?> ANSWER

6 Diagnostic Reference Levels:

- [ ] They represent the limit to patient dose.
- [ ] Are independent of the anatomical region.
- [x] Are a tool for optimisation of patient dose.
- [ ] If exceeded for a patient, it indicates bad practice.

/ Test Your Knowledge

<?> QUESTION

7

Which of the following statements regarding limits of radiation exposure is/are correct?

- ☐ There is no limit of radiation dose for the patient.
- ☐ The limit for occupationally exposed personnel is 1 mSv per month.
- ☐ The limit for occupationally exposed personnel is 20 mSv per year.
- ☐ There is no limit of radiation dose for the public.

/ Test Your Knowledge

<?> ANSWER

7 Which of the following statements regarding limits of radiation exposure is/are correct?

- [x] There is no limit of radiation dose for the patient.
- [ ] The limit for occupationally exposed personnel is 1 mSv per month.
- [x] The limit for occupationally exposed personnel is 20 mSv per year.
- [ ] There is no limit of radiation dose for the public.

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