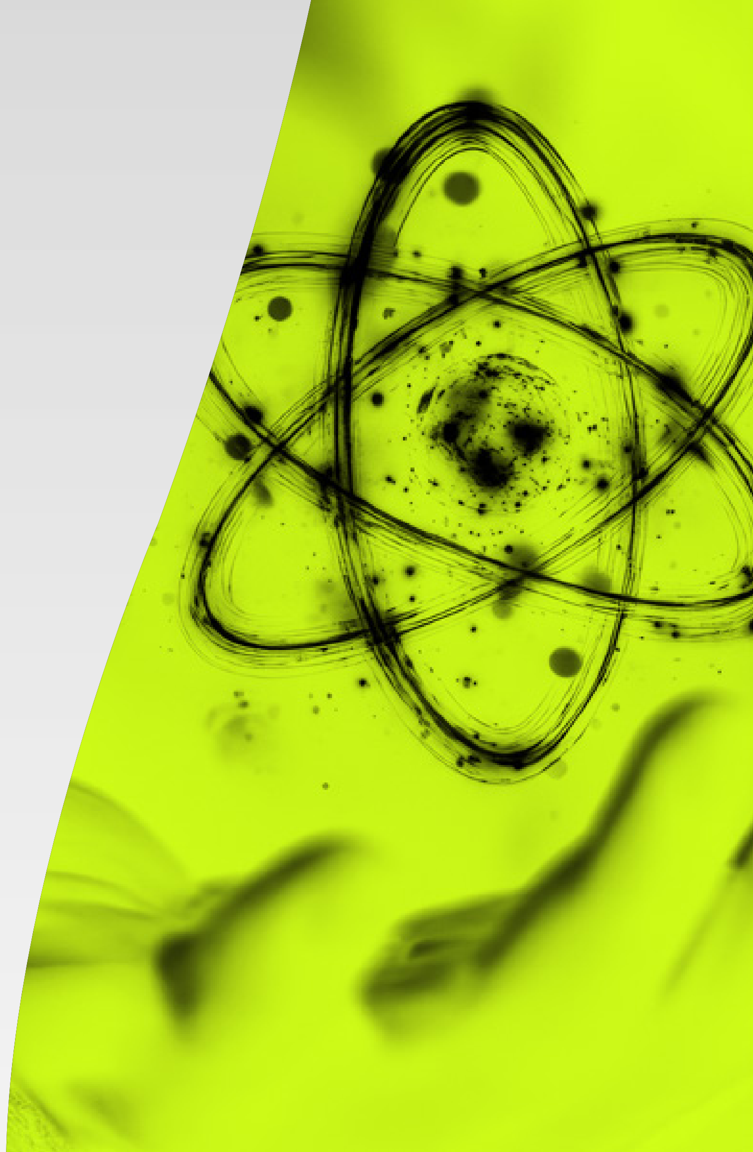
MODERN RADIOLOGY
eBook

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

放射生物学原理和辐射防护



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:

/ 放射生物学原理和辐射防护

章节大纲：

/ 前言

*《现代放射学》*是由欧洲放射学协会 (European Society of Radiology, ESR) 在线发布的免费放射学教育资源。第二版（更名版）标题反映了 *ESR 电子书*新颖的教学概念，它以简洁页面的形式巧妙地融合文本、图像和示意图，并辅以临床影像学案例、问答部分和内容超链接，使读者能够在各基于器官的部分、更具技术性的章节、摘要以及参考文献之间快速切换浏览。

其章节以 100 多名公认欧洲专家的优秀稿件为根基，涉及各类一般技术和基于器官的临床影像学主题。同时采用了全新的图形外观，展示了佩戴时尚眼镜的 Asklepios，象征着传统医学教学与现代风格教育的结合。

虽然初版 *ESR 电子书*旨在为医学生和本科生教师提供医学基础知识，但现已逐渐扩充其知识领域，为希望"深入挖掘"的读者提供了更多高阶技术知识。因此，*《现代放射学》*还涵盖了*欧洲放射学培训课程*研究生水平的各类主题，旨在解决住院医师的研究生教育需求。此外，书中还囊括了全球医疗专业人士的反馈，他们希望更新自己在医学影像特定领域的知识，并对 *ESR 电子书*在基础和高等教育水平上的深度和清晰度表示高度赞赏。

我要衷心感谢所有为这项非营利活动自愿贡献时间和专业知识的作者，以及最初提出创作 *ESR 电子书*的 Carlo Catalano、Andrea Laghi 和 András Palkó，最后还要感谢 ESR 办公室所提供的技术和行政支持。

*《现代放射学》*充分体现了医者的协作精神和对这门热门医学学科坚定不移的承诺，这是现代患者护理必须具备的优秀精神品质。我希望这款***教育***工具能够激励各位始终保持好奇心和批判性思维，从而促进整个欧洲乃至欧洲以外地区对放射学艺术和科学的认识。

Minerva Becker，编辑
瑞士日内瓦大学放射学教授

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Translation Credits

This is a translation of the Chapter of the **Modern Radiology eBook.**

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Chinese Society of Radiology

NOTE FROM THE COORDINATORS:
Thank you to Chinese radiology experts for bridging languages and open the world-class English resource by ESR to every Mandarin-speaking student, fueling global radiology talent with a single click

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

CHAPTER OUTLINE:

放射生物学原理和辐射防护

章节大纲：

翻译致谢

本章节为《现代放射学电子书》的部分译文。

原文标题：
放射生物学原理和辐射防护

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中华医学会放射学分会

译者寄语：
感谢中国放射学专家们的倾力奉献！你们跨越了语言的鸿沟，将欧洲放射学会 (ESR) 的世界级学术宝库呈献给广大中文学子。如今，前沿智慧一键即达，为全球放射学人才的蓬勃发展注入了强劲动力。

<> 超链接

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/ Signage

<■> **CORE KNOWLEDGE**

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>|< **COMPARE**

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<!> **注意**

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<∞> **参考文献**

MODERN RADIOLOGY eBook

Based on the ESR Curriculum for Radiological Education

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

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

CHAPTER OUTLINE:

放射生物学 原理和 **辐射防护**

基于 **ESR** 课程的放射学教育

章节大纲：

放射生物学 原理和 辐射防护

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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
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CHAPTER OUTLINE:

章节大纲：

/ 工作团队

本电子书各章节中包含的大部分图片和部分文本基于日内瓦大学医院（日内瓦大学医院 (HUG)，瑞士日内瓦）、洛桑大学医院（沃州大学中心医院 (CHUV)，瑞士洛桑）和苏黎世大学医院（苏黎世大学医院 (USZ)，瑞士苏黎世）的辐射防护与医学物理团队制作的在线学习模块。

上述在线学习模块的插图由 Rosaria Marraffino（Rosaria Marraffino，负责在线学习与沟通）创作。本版电子书各章节中的插图有所调整，经过了这三家大学医院和 Rosaria Marraffino 女士许可。

<∞> 参考文献

https://www.hug.ch/
https://www.chuv.ch/fr/chuv-home
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CHAPTER OUTLINE:

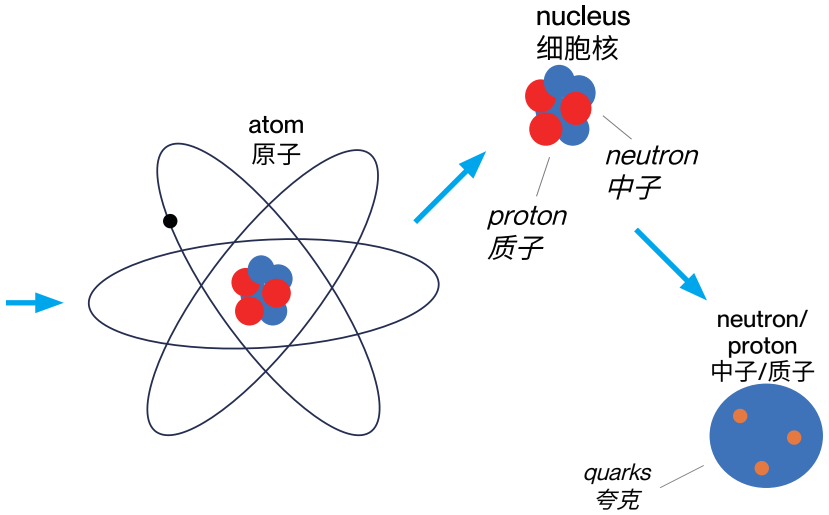
章节大纲：

/ 电离辐射

/ 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.



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

CHAPTER OUTLINE:

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章节大纲：

/ 物质的组成成分

物质由形成固体、液体或气体的分子组成。分子由原子组成。**原子**是保持元素所有化学性质的最小物质单元。原子由位于原子核中的**质子**（正电荷，+1）和**中子**（无电荷）以及位于原子核周围轨道中的**电子**（负电荷，-1）组成。质子和中子的质量大致相同（1.67×10^{-24} 克），被定义为一个原子质量单位 (amu) 或 1 道尔顿。原子呈电中性。

夸克是构成质子和中子的无结构的亚原子粒子。每个质子和每个中子都有 3 个夸克。

/ 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.

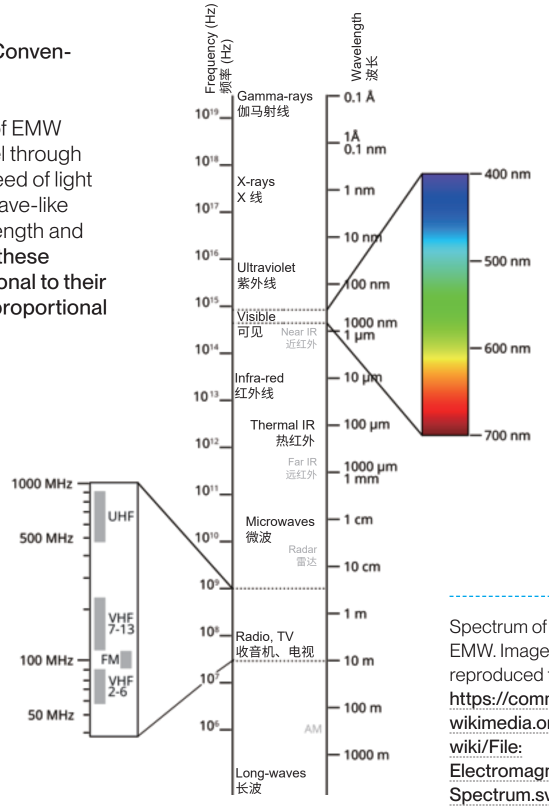
> See eBook chapter on Conventional X-Ray Imaging.

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 frequency and inversely proportional to their wavelength.**

<!> ATTENTION

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

- / **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

MODERN RADIOLOGY

/ Principles of Radiation Biology and Radiation Protection

CHAPTER OUTLINE:

/ 放射生物学原理和辐射防护

章节大纲：

/ 电磁波 (EMW)

电磁波 (EMW) 是一种以光速在空间中传播的能量形式。电磁波由彼此垂直传播并与波行进方向垂直传播的**振荡电场和磁场组成**。

电磁波覆盖的**范围非常广泛**，包括无线电波、微波、红外线、可见光、紫外线、X 线和 γ 线。X 线是在 X 线管中产生的电磁波。

> 请参阅《常规 X 线成像》电子书章节。

电磁波的共同特征包括在真空中行进的能力、速度（光在真空中的速度为 c）和波的性质，例如波长和频率。**电磁波的能量与其频率成正比，与其波长成反比。**

<!> 注意

$$波长 = \frac{真空中的光速（c=300，000\ km/s）}{频率}$$

- / **辐射 = 运动中的能量。**
- / **电磁辐射或“电磁射线”（以光速传播）必须与微粒辐射或“粒子束”（以低于光速传播）区分开来。**
- / 粒子束包括电子、质子、α 粒子、中子。

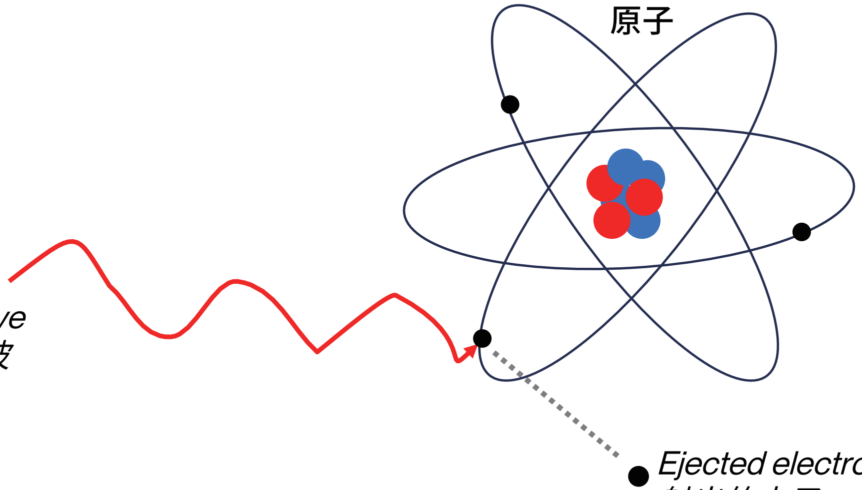
电磁波谱。图片来源：https://commons.wikimedia.org/wiki/File:Electromagnetic- Spectrum.svg

/ 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



CHAPTER OUTLINE:

章节大纲：

/ 电离过程

/ 电离过程是指电中性原子通过失去或获得电子转化为带电荷原子或分子（即离子）的过程。

/ 辐射（例如，X 线和粒子）能够将电子从原子中脱离。

/ 在此过程中，辐射损失其传递给物质的能量。这种由电子积存的能量将决定辐射剂量。
> 见下页

/ Types of Ionising Radiation

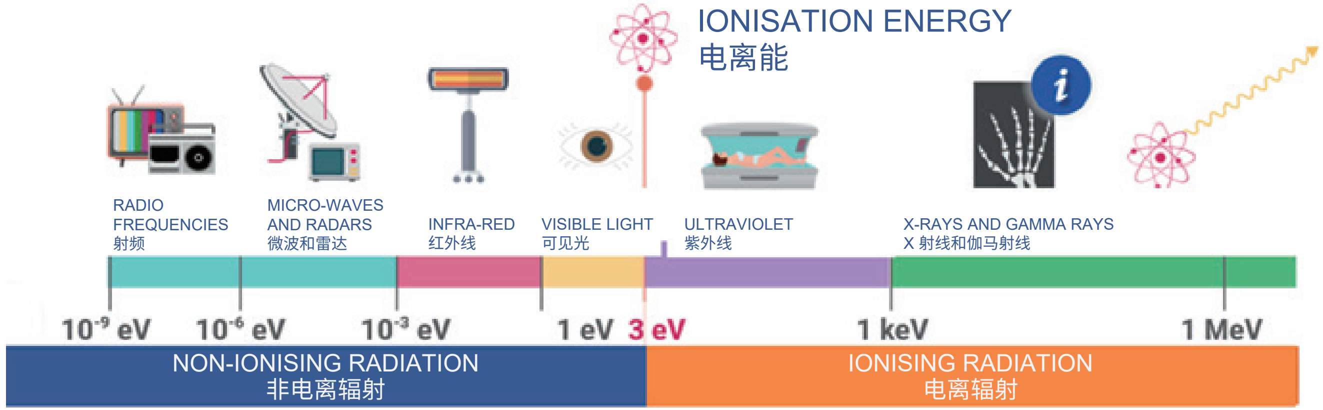
A key difference among EMW is their **ability to ionise atoms or molecules**. This ability depends on the **energy of the wave**, which increases with frequency.

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!



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章节大纲：

/ 电离辐射类型

各类电磁波之间的关键区别之一是其**电离原子或分子的能力**。这种能力取决于**波的能量**，其随频率的增加而增加。

具有**较高频率**的电磁波（例如紫外线、X 线和 γ 线）具有足够的能量来电离原子，被称为**电离辐射**。

相比之下，无线电波、微波和可见光等低频波的能量不足以引起电离，因此被视为**非电离辐射**。

<!> 注意

电磁波 (EMW) → 仅部分电磁波具有电离功能！

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.

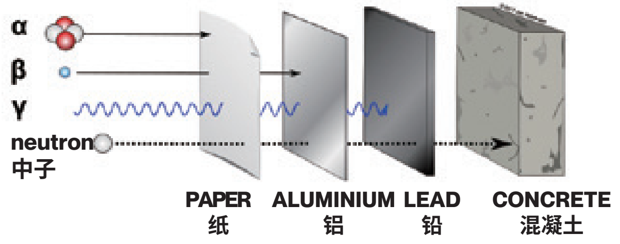
Gamma radiation: a **photon of energy** (no mass, EMW) is emitted from an unstable nucleus. Photons can travel much farther than alpha and beta particles

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:
可电离的微粒：

Penetrating power of different types of radiation
不同类型辐射的穿透力



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

CHAPTER OUTLINE:

放射生物学原理和辐射防护

章节大纲：

α 辐射：发生在一些放射性核素的放射性衰变（α 衰变）期间，例如，铀 238、镭 226、钋 210，其可释放出 α 粒子（即 2 个质子 + 2 个中子，也就是双电离氦原子）。α 粒子运动缓慢、重量大、高度电离（带双正电荷），无法传播很远（在空气中只有几厘米）。这些粒子不能穿透皮肤外层，但如果从食物中摄入或从空气中吸入，会导致严重的细胞损伤。

β 辐射：发生在原子核发射 β 粒子的放射性衰变期间。**β 粒子**（即高能量的高速电子或正电子）比 α 粒子的电离能力弱，可以传播更远的距离（在空气中为几米）。这些粒子可以穿透几厘米的皮肤。

γ 辐射：能量光子（无质量，EMW）由不稳定的原子核发射。光子的传播距离远于 α 粒子和 β 粒子

X 射线辐射：由电子的能量变化产生。**X 线** (EMW) 在 X 线管中生成。X 射线的能量通常低于 γ 射线。

中子辐射：自由中子由富中子核和贫质子核中发生的核裂变产生。中子可在空气中传播数千米。中子不直接电离原子，而是被稳定的原子吸收，使原子变得更加不稳定。不稳定的原子会发射电离辐射（**间接电离**）。

图片来源：https://commons.wikimedia.org/wiki/File:Penetrating_power_of_different_types_of_radiation_-_alpha,_beta,_gamma_and_neutrons.svg

Dose Quantification

剂量测定

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

放射生物学 原理和 **辐射防护**

CHAPTER OUTLINE:

章节大纲：

/ 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

↓

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

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

CHAPTER OUTLINE:

/ **放射生物学原理和辐射防护**

章节大纲：

/ 吸收剂量 (D)

/ 吸收剂量 (D) 定义为每单位质量受辐射物质通过电离辐射传递的能量。

/ 吸收剂量是一个可测量的量。

/ 所有类型的电离辐射的吸收剂量均可测量。

/ 吸收剂量的单位为戈瑞 [Gy] → 1 Gy = 1 J/kg。

/ 吸收剂量描述的是辐射向体内任意部位组织体积中沉积的能量。这一术语用于评估组织中**生化变化的可能性**。

可测量的量

↓

$$D = \frac{能量}{肿块} \quad \frac{[J]}{[kg]}$$

/ 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

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

/ **放射生物学**原理和**辐射防护**

/ 当量剂量 (H)

/ 并非所有类型的辐射都会引起相同的生物损伤。

/ 辐射权重因子 W_R 可反映辐射类型在产生生物损伤时的相对有效性。

/ 吸收剂量与辐射权重因子 W_R 的乘积称为**当量剂量 H**。

/ 当量剂量的单位为希沃特 [Sv] → 1 Sv=1 J/kg。

/ H 考虑了**不同辐射类型的破坏性**。

辐射类型	辐射权重因子 W_R
X 线、γ 线、β 粒子	1
质子	2
中子*	2.5～20
α 粒子和多电荷粒子	20

*中子的 W_R 是能量的连续函数

/ 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)

CHAPTER OUTLINE:

章节大纲：

/ 有效剂量 (E)

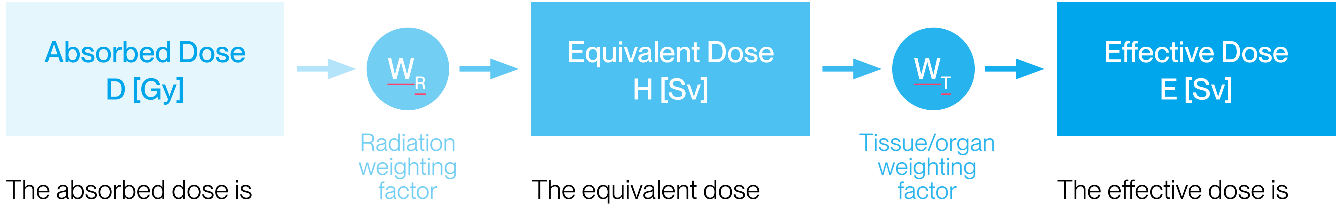
- / 不同类型的组织对辐射的敏感性有所区别。
- / 组织权重因子 W_T 反映了特定组织受照射所致随机性效应的健康危害相对于均匀全身照射时该危害所占的比例。
- / W_T 针对的是性别数量相当、年龄范围宽泛的参考人群。
- / 有效剂量 (E) 是各器官的当量剂量与其权重因子的乘积之和。
- / 有效剂量的单位为希沃特 [Sv]。
- / E 考虑了不同组织的辐射敏感性。

器官/组织	W_T
乳腺、骨髓、结肠、肺、胃，其余组织*	0.12
性腺	0.08
膀胱、食管、肝、甲状腺	0.04
骨表面、脑、唾液腺、皮肤	0.01
总计	1

*其余组织为肾上腺、胸腔外组织、胆囊、心脏、肾脏、淋巴结、肌肉、口腔黏膜、胰腺、前列腺（男性）、小肠、脾脏、胸腺、子宫/子宫颈（女性）

/ Absorbed Dose, Equivalent Dose and Effective Dose

<!> ATTENTION



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.

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

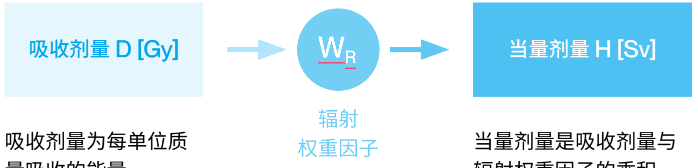
CHAPTER OUTLINE:

/ **放射生物学原理和辐射防护**

章节大纲：

/ 吸收剂量、当量剂量和有效剂量

<!> 注意

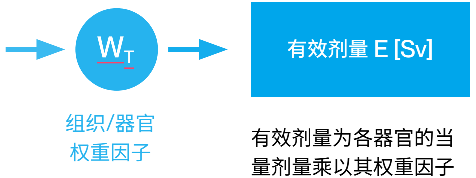


吸收剂量为每单位质量吸收的能量。

单位为 Gy。

当量剂量是吸收剂量与辐射权重因子的乘积。

单位为 Sv。



有效剂量为各器官的当量剂量乘以其权重因子的乘积之和。

单位为 Sv。

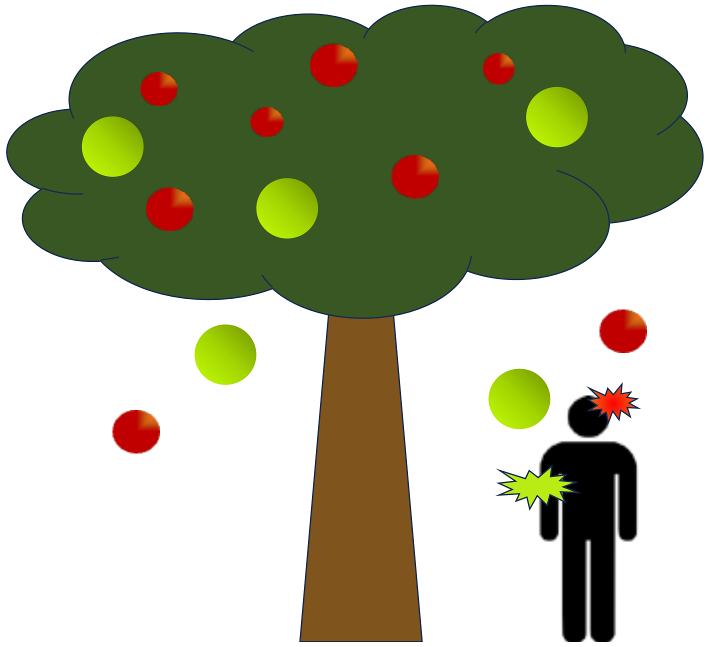
<!> ATTENTION

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 bio-logical 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).**



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

放射生物学原理和辐射防护

<!> 注意

使用苹果树进行类比

落在人身上的苹果所积存的能量以戈瑞 > **吸收剂量 (D)** 来测量。

不同类型苹果（绿色或红色）对产生生物损伤的功效不同，以希沃特 > **当量剂量 (H)** 来表示。

苹果对人体的撞击位置不一样，影响也不尽相同。考虑辐照区域的辐射敏感性，以希沃特 > **有效剂量 (E)** 表示。

/ Effects on the Human Body

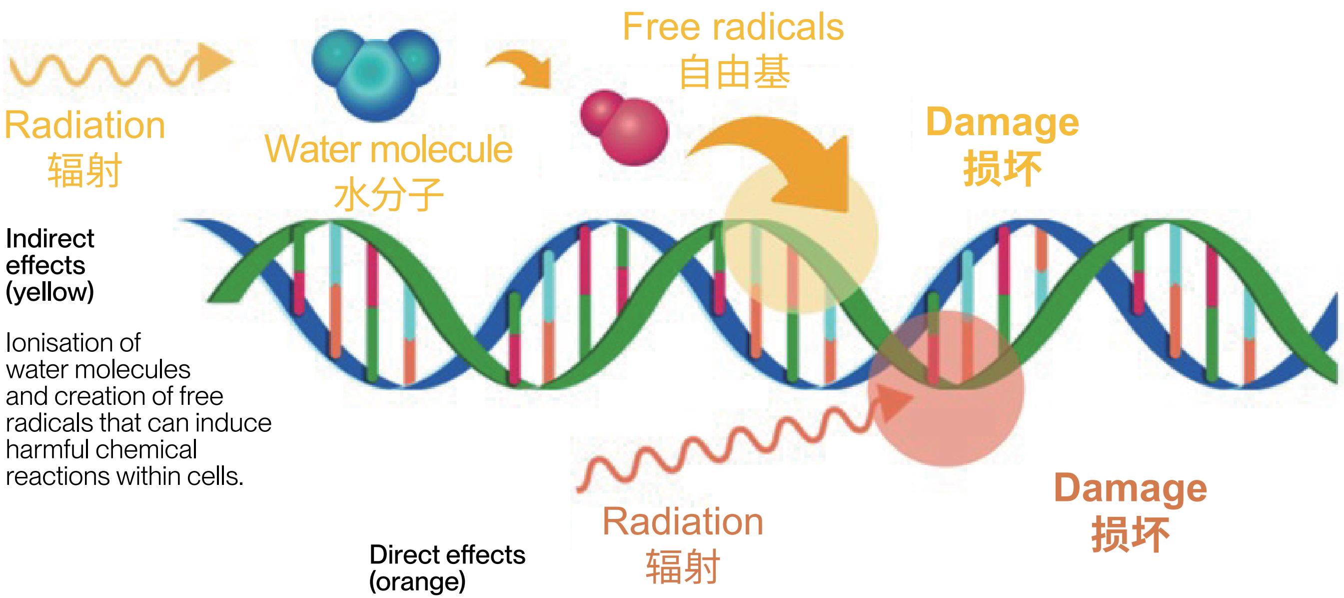
/ Principles of **Radiation Biology** and **Radiation Protection**

/ **放射生物学**
原理和
辐射防护

/ 对人体的影响

/ Interactions of Ionising Radiation With the Cell

<!> ATTENTION



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.

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

CHAPTER OUTLINE:

/ **放射生物学原理和辐射防护**

章节大纲：

/ 电离辐射与细胞的相互作用

<!> 注意

间接影响（黄色）

水分子的电离和自由基的产生，可诱发细胞内的有害化学反应。

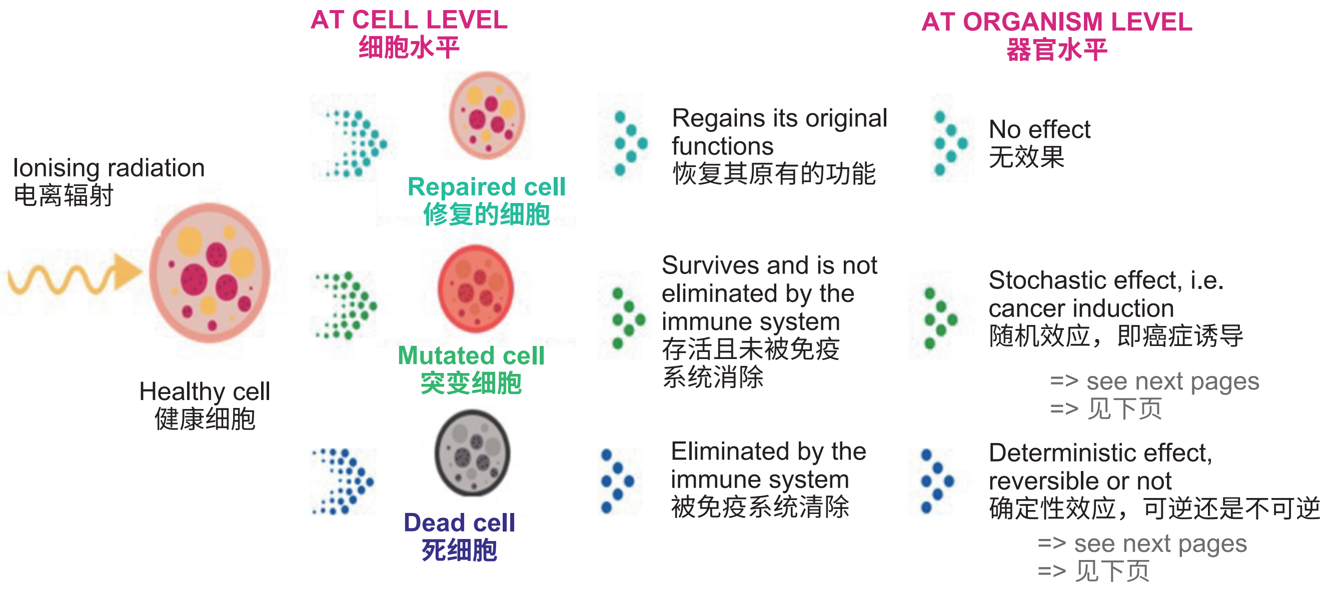
直接影响（橙色）

DNA 分子中原子的电离产生能够破坏 DNA 的离子。

/ Effects of Radiation Exposure

<!> ATTENTION

DNA damage can lead to one of the following effects:



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

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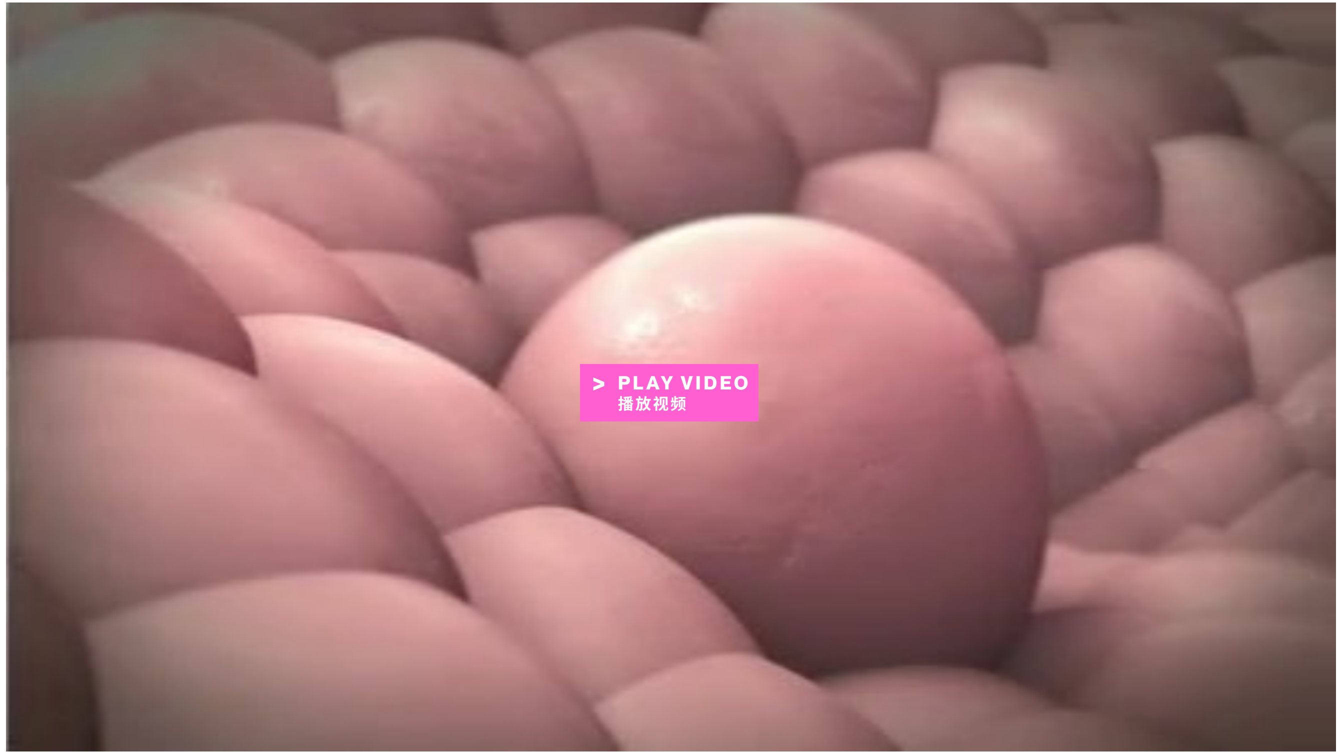
/ 辐射暴露的影响

<!> 注意

章节大纲：

DNA 损伤可导致以下影响：



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

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

CHAPTER OUTLINE:

放射生物学原理和辐射防护

章节大纲：

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

<!> ATTENTION

A cell is more sensitive to radiation when:

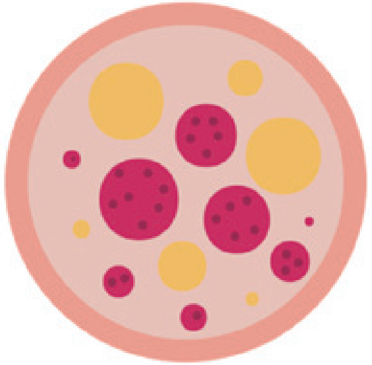
It is young
它很年轻

It is poorly differentiated
它的分化性很差

It has a fast turnover rate
它具有快速的周转率

This is why children are more sensitive to radiation than older people.
这就是儿童比老年人对辐射更敏感的原因。

Reasons why some tissues are more sensitive than others.
一些组织比其他组织更敏感的原因。



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.

Principles of Radiation Biology and Radiation Protection

放射生物学原理和辐射防护

CHAPTER OUTLINE:

章节大纲：

<!> 注意

细胞在以下情况下对辐射更敏感：

根据贝戈尼-特里邦多定律，生物组织的辐射敏感性与其有丝分裂活性成正比，与其细胞分化程度成反比。换言之，细胞的高增殖速率和组织的高生长速率导致辐射敏感性增加。

/ 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 确定性	versus 对比 STOCHASTIC 随机
DOSE LEVEL 剂量水平	« High » doses 【高】剂量	Already at low doses 本身剂量较低
THRESHOLD 阈值	Threshold demonstrated (General value: 0,5 Gy) 显示阈值（一般值：0.5 Gy）	No threshold demonstrated 未证明阈值
MECHANISMS 机制	Cellular destruction: loss of functionality of a tissue/organ 细胞破坏：组织/器官功能丧失	Cellular modification: induction of cancer, other somatic diseases 细胞修饰：诱导癌症和其他躯体疾病
DELAYS 延迟	Short 短	Latency up to several years 潜伏期长达数年
VARIATION WITH DOSE 随剂量的变化	Severity 严重程度	Probability of dying from cancer 因癌症死亡概率 ↗ 5% / Sv

/ 辐射效应的特征

<!> 注意

辐射对生物系统的影响因辐射类型、剂量、暴露持续时间和暴露的生物系统而异。

辐射效应可分为随机性（偶然性）与确定性、急性与慢性、直接与间接、全身与局部。

>|< 比较

>|< 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.

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

CHAPTER OUTLINE:

放射生物学原理和辐射防护

章节大纲：

>|< 比较

<!> 注意

急性效应与慢性效应

- 短期高剂量照射可导致急性反应，往往立即引起症状。这些并发症可能包括放射性烧伤、急性辐射综合征 (Acute Radiation Syndrome, ARS) 和组织损伤。
- 长期的低水平暴露所导致的慢性效应，常在暴露后数年出现。慢性效应可能包括癌症、心血管疾病和白内障。

直接效应与间接效应 > 见第 21 页

- 直接效应：辐射直接电离 DNA 中的原子，导致突变和细胞死亡。
- 间接效应：辐射会电离体内的水分子，产生可损害 DNA 和其他细胞结构的自由基。

全身效应与局部效应

- 当辐射波及全身时，会产生全身效应，例如放射病。
- 当身体的特定区域暴露于辐射时，就会发生局部效应，例如局部组织损伤或烧伤。

累积效应

- 反复暴露会增加风险和严重程度。人体具有一定的修复辐射损伤的能力，但反复暴露可破坏这些机制。

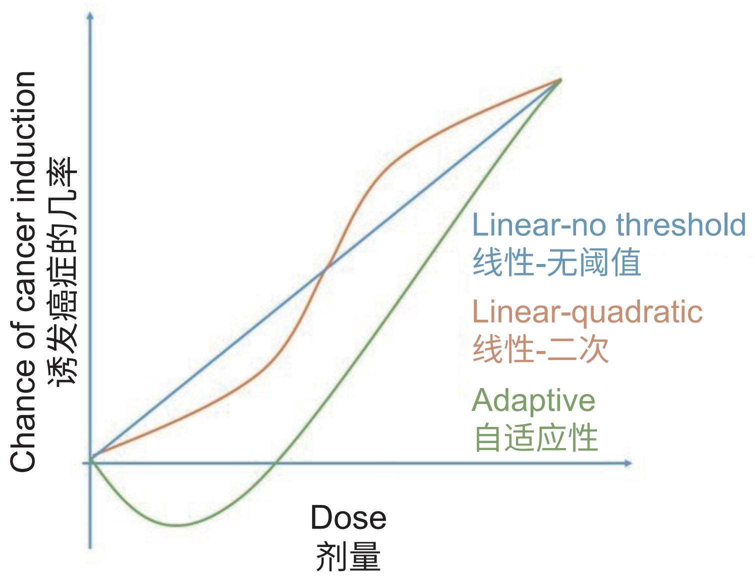
/ Stochastic Effects – The Linear Non-Threshold Model

<!> 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

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

/ **放射生物学** 原理和 **辐射防护**

CHAPTER OUTLINE:

章节大纲：

/ 随机性效应 - 线性无阈模型

<!> 注意

辐射防护中可使用不同的模型以估算电离辐射的随机健康效应。

最常用的模型是线性无阈 (LNT) 模型。

监管机构通常使用 LNT 来制定卫生管理政策。

辐射防护中使用不同的模型来估算辐射随机性效应。
来源：https://radiopaedia.org/articles/5099

/ 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%.

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

CHAPTER OUTLINE:

/ **放射生物学**原理和**辐射防护**

章节大纲：

/ 随机性效应 - 终生归因风险 (LAR)

终生归因风险 (LAR) = 个体由于在其一生中暴露于诸如辐射的危险而患特定疾病（通常为癌症）的概率。这代表了**高于基线风险的额外风险**（在未暴露于任何有害因素的情况下发生疾病的风险）。

与辐射相关的 LAR 关键特征包括：

/ 累积性质，反映了终生辐射暴露的疾病风险

/ 这是一个基于人群的指标，来源于类似原子弹爆炸幸存者的研究。

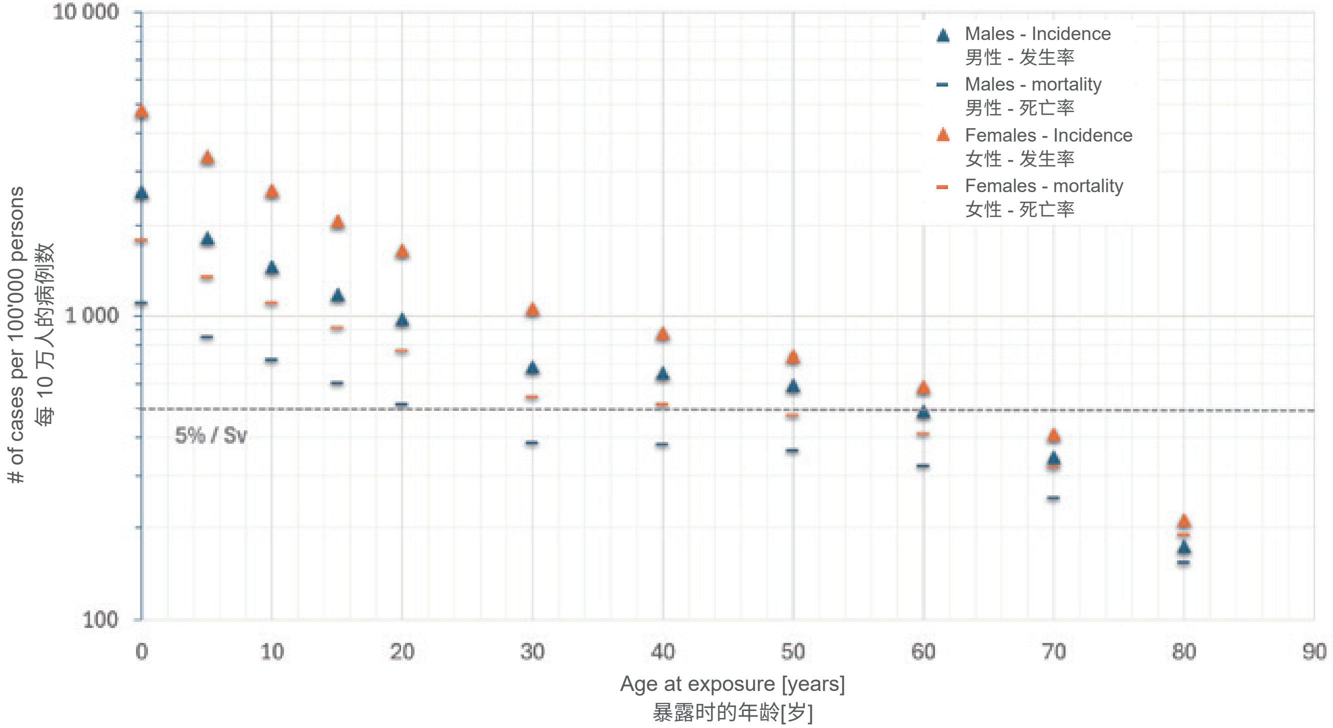
/ 因年龄和性别而异，最常用于癌症，但也适用于其他疾病

/ 存在剂量-效应关系，且风险随辐射剂量增加而增加

/ 通常表示为概率

LAR 在各种情况下对**辐射的长期健康影响**的风险评估中至关重要，并为美国国家环境保护局 (EPA) 和国际放射防护委员会 (ICRP) 等监管机构制定的指南提供信息基础。

计算示例：如果暴露于辐射的 100,000 人中额外出现 500 例癌症病例：癌症的 LAR = 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.

Principles of Radiation Biology and Radiation Protection

CHAPTER OUTLINE:

放射生物学原理和辐射防护

章节大纲：

单次给药剂量为 0.1 Gy 时，实体瘤发生/死亡的终生归因风险 (LAR)。
来源：数据摘自以下出版物的表 12D-1 和 12D-2： Health Risks from Exposure to Low Levels of Ionising Radiation: BEIR VII – Phase 2.

/ 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

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

CHAPTER OUTLINE:

/ **放射生物学原理和辐射防护**

章节大纲：

/ 确定性效应

<!> 注意

/ 确定性效应具有一个**阈值**，低于该阈值时不会发生该效应。

/ 当效应发生时，其**严重程度取决于辐射剂量**。

确定性效应和发生时间的示例

效应	剂量阈值 [GY]	发生时间
白内障	0.5	数年
皮肤红斑	2~6	小时/周
不育	4~6（男性） 4~20（女性）	3 周 < 1 周
毛发脱落	7	3 周
不可逆的皮肤损伤	18	> 10 周
致死率（全身照射）	3~5	30~60 天

/ 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).

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

CHAPTER OUTLINE:

/ **放射生物学**
原理和
辐射防护

章节大纲：

/ 宫内暴露

>|< 比较

与成人相同，对于子宫内暴露，电离辐射可能导致两种效应：

确定性效应：

/ 效应发生在 100 mGy 的阈值以上。

/ 效应取决于妊娠阶段：不同的受损器官（畸形、IQ 降低）。

/ 效应随剂量增加而增强。

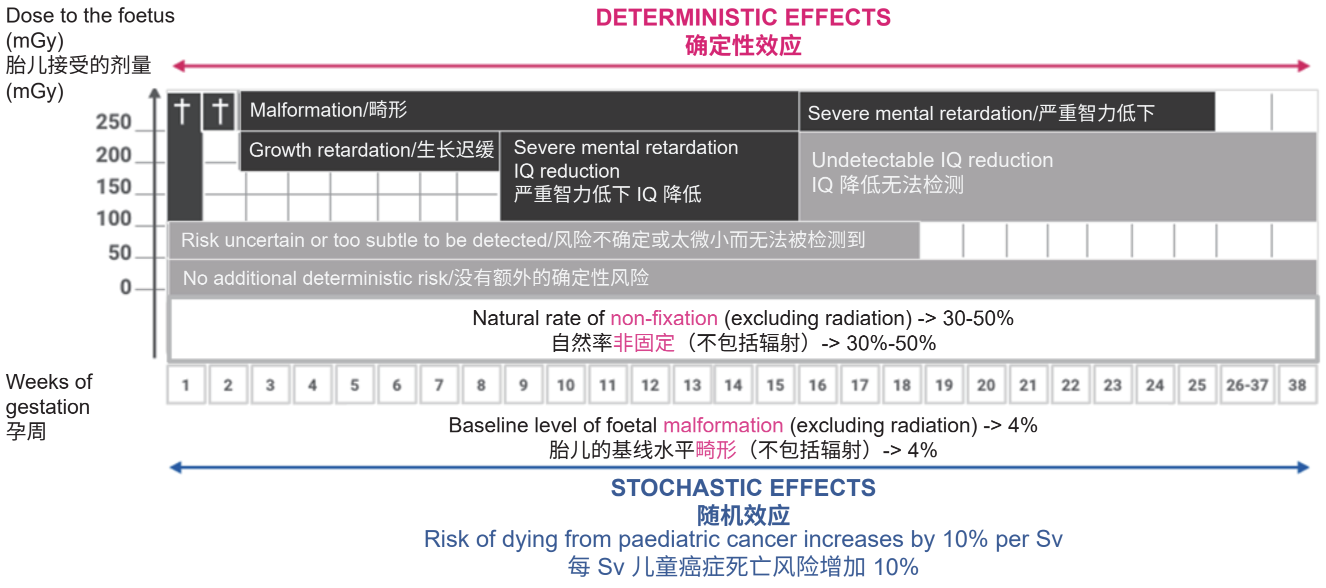
随机性效应：

/ 从胚胎着床到妊娠结束期间均存在随机风险。

/ 胎儿（每 Sv 为 10% 至 20%）的发生概率高于成年人（每 Sv 为 5%）。

/ In Utero Exposure

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



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

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/ 宫内暴露

具体效应因孕周而异：

Sources of Exposure and Order of Magnitude

CHAPTER OUTLINE:

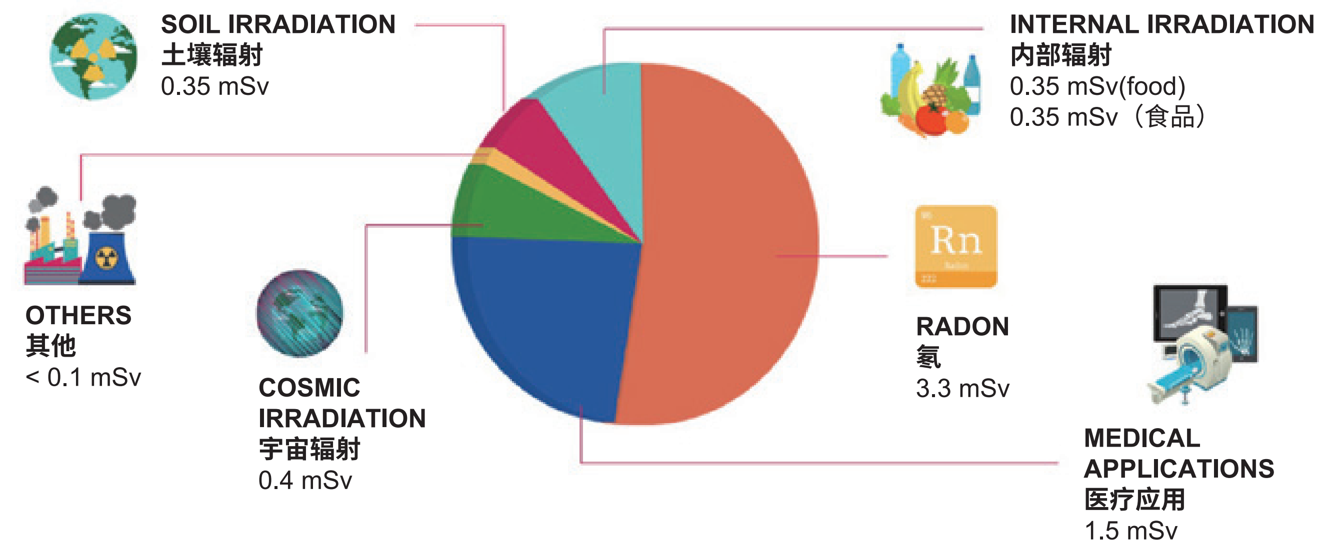
章节大纲：

暴露来源和数量级

/ 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).

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

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章节大纲：

/ 辐射暴露来源

人类每天都暴露在天然或人工的放射性环境中。

暴露因人而异，具体取决于地点和生活方式。

本图中的数字为瑞士人口的暴露数据。瑞士人均年有效剂量为 6 mSv。来源：数据摘自 2022 年 BAG 报告（取整值）。

/ Global Medical Radiation Exposure

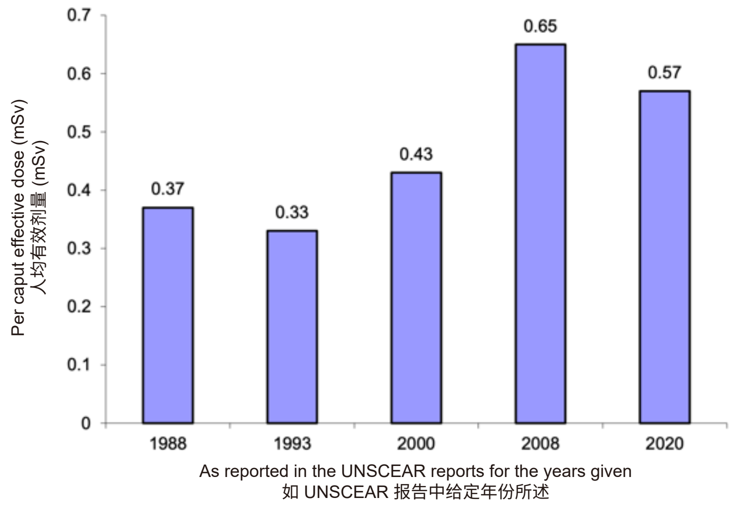
Medical exposure is the **largest human-made source** of radiation exposure globally.

/ 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.

Annual effective dose per caput from different UNSCEAR medical exposure evaluations
来自不同 UNSCEAR 医疗暴露评估的人均年有效剂量



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

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

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CHAPTER OUTLINE:

章节大纲：

/ 全球医学辐射暴露

医学辐射暴露是全球最大的人工辐射来源。

/ 2020 年，针对全球 73 亿人口进行了约 42 亿次医学放射学检查，产生了显著的集体辐射剂量。

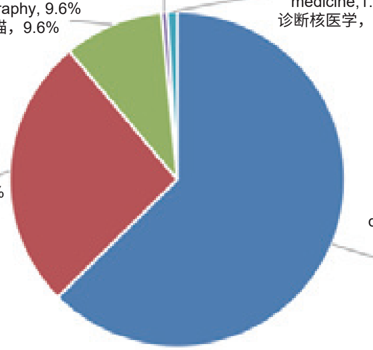
/ 2020 年，除放疗外，全球人群接受这些医疗程序的人均有效剂量为 0.57 mSv。

/ 由于数据缺口和不同地区每次检查的剂量差异，这些估计值存在高度**不确定性** (±30%)。这些数据**未考虑**职业辐射暴露。

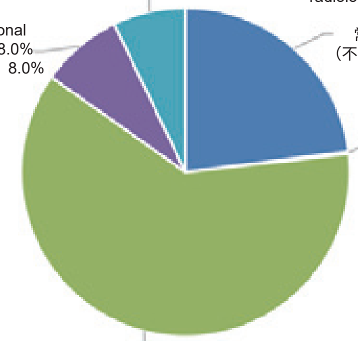
来源：UNSCEAR report 2020/2021 – Volume 1 Scientific Annex A.
https://www.unscear.org/unscear/uploads/documents/unscear-reports/UNSCEAR_2020_21_Report_Vol.I.pdf

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

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

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章节大纲：

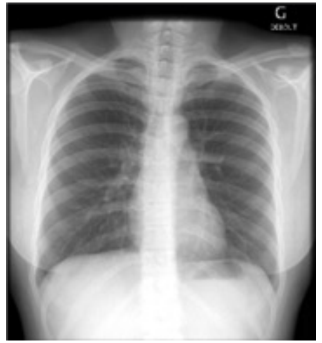
每种影像学检查方法的医疗程序和剂量（不包括放疗）

(a) 检查/程序

(b) 集体有效剂量

按影像学检查方法划分的检查/程序分布 (a) 及其对不包括放疗的医疗暴露的**集体有效剂量的贡献** (b)。
来源：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

/ 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**

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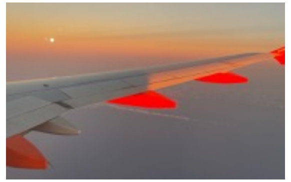
章节大纲：

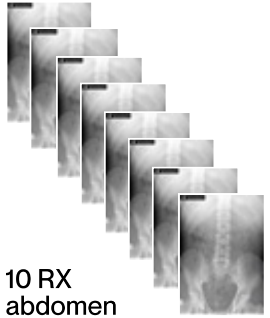
/ 不同成像模式的成人有效辐射剂量示例

影像学检查类型	有效剂量 (mSv)	相当于自然辐射在...期间的剂量
四肢（手、脚）X 线检查	0.001	2 h
牙科 X 线检查	< 0.01	< 1 天
胸部 X 线检查	0.05	4 天
头部 X 线检查	0.05	4 天
乳腺 X 线摄影（4 次采集）	0.1	8 天
腹部 X 线检查	0.7	2 个月
骨盆 X 线检查	1	3 个月
头颅 CT	2	6 个月
胸部 CT 扫描	3.5	1 年
腹部 CT	8	2 年

/ Order of Magnitude

1 CT abdomen ≈ 8 mSv (1 acquisition)

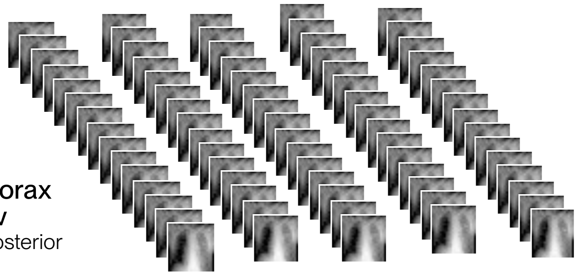




≈ 100 flights GVA ⇄ JFK

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

10 RX abdomen ≈ 0.8 mSv



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

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

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章节大纲：

/ 数量级

1 次 CT（腹部）≈ 8 mSv（采集 1 次）

≈ 100 次飞行（GVA ⇄ JFK）

以日内瓦 > 纽约的航班为例，飞行中的照射剂量 = 0.0432 mSv
飞行时间 = 9 小时

10 次 RX（腹部）≈ 0.8 mSv

80 次 RX（胸部）≈ 0.1 mSv（前后位和侧位）

/ Radiation Protection Principles

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

CHAPTER OUTLINE:

/ **放射生物学** 原理和 **辐射防护**

章节大纲：

/ 辐射防护原则

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**

放射生物学原理和辐射防护

CHAPTER OUTLINE:

章节大纲：

科学背景、准则、标准和法规

国际科学研究：

根据在不同国家进行的研究，在国际层面达成科学共识（即 UNSCEAR*）。

一般原则和准则：

国际放射防护委员会 (ICRP) 基于科学、经济和社会方面的考虑，提出了管理辐射风险的方法。

监管前标准：

政府间国际组织（IAEA**、Euratom***）为各国制定标准，这些标准或多或少具有法律约束力。

国家层面的法规：

国家层面的法规旨在保护接触电离辐射的工作人员、公众和患者。

* **联合国原子辐射影响科学委员会 (UNSCEAR)** 成立于 1955 年，其宗旨是收集并分析各种来源的数据，开展有关辐射生物影响的科学研究，并评估相关的健康风险。UNSCEAR 向联合国提供科学咨询意见，指导制定国际辐射防护标准。UNSCEAR 发布供全球各国政府和研究人员使用的综合报告，并与国际原子能机构 (IAEA) 和世界卫生组织 (WHO) 等组织合作，确保全球标准得到科学证据的支持。

** **国际原子能机构 (IAEA)** 成立于 1957 年，旨在促进和平利用核能并防止核武器扩散。作为一个独立的联合国机构，IAEA 协助各国将核能用于电力、医疗和农业，同时通过国际标准提供安全和保障。IAEA 实施保障措施以落实不扩散的原则，支持科学研究并提供培训。IAEA 开展国际合作，推动安全核技术用于全球发展和医疗卫生等领域。

*** **欧洲原子能共同体**成立于 1957 年，致力于协调和促进欧盟成员国之间核能的和平使用。其主要职能包括确保核安全、支持研发、保护核材料、监管核燃料供应以及代表成员参与国际协议。尽管近年来逐渐转向可持续能源政策，但原子能共同体在其自身法律框架下运作，对欧盟内部的核安全、研究和监管仍然至关重要。

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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Official Journal of the European Union

L 13

English edition   Legislation

Volume 57
17 January 2014

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

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

CHAPTER OUTLINE:

放射生物学原理和**辐射防护**

章节大纲：

<!> 注意

欧洲原子能共同体理事会第 2013/59 号指令，2013 年 12 月 5 日

第 III 章

辐射防护体系

第 5 条

辐射防护的一般原则

来源：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.

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

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章节大纲：

/ 正当性

<!> 注意

一项活动的正当性通过以下因素来考量：

/ **相关获益明显超过辐射危害**

/ 通常没有对人类和环境更为有利的替代方案

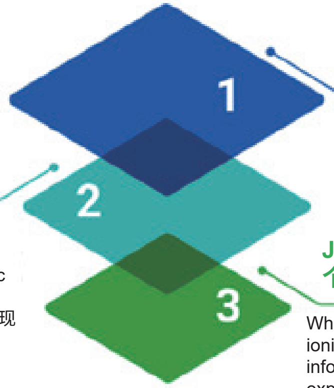
这一原则可以概括为：***“利大于弊”***

示例：

/ 使用荧光透视装置复位骨折。

/ 使用 CT 扫描仪进行诊断。

/ Justification - Three Levels of Justification in Medicine



FUNDAMENTAL JUSTIFICATION
基本正当性

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.
该学会认为，当电离辐射允许做出诊断或治疗病理时，使用电离辐射是合理的。

JUSTIFICATION OF DIAGNOSTIC OR THERAPEUTIC PROCEDURES
诊断性或治疗性操作的正当性

The widespread application of a procedure must be justified → no other existing procedure with less radiation is as effective (recommendations of scientific societies).
必须证明程序的广泛应用是合理的 → 其他辐射较少的现有程序无法实现同效（科学学会建议）。

JUSTIFICATION OF INDIVIDUAL APPLICATIONS
个体患者医疗程序的正当性

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.
当医生开具涉及电离辐射的处方或进行检查时，他/她必须考虑可用的诊断信息和患者的史→以避免不必要的暴露。

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

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

/ 放射生物学原理和辐射防护

CHAPTER OUTLINE:

章节大纲：

/ 正当性 - 医学中正当性的三个层次

开具放射学检查或操作处方的医生和**执行**这些操作的医生负责应用正当性原则。

/ Optimisation

<!> ATTENTION

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

As

Low

As

Reasonably

Achievable

DOSE

DOSE

/ 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.

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章节大纲：

/ 最优化

<!> 注意

优化原则也称为 **ALARA**（As Low As Reasonably Achievable，尽可能低且合理）原则：

As

Low

As

Reasonably

Achievable

剂量

剂量

/ 必须找到最佳的获益/风险比。

/ 还必须考虑到经济和社会等方面。

这包括优化程序、采取保护措施并不断努力尽量减少暴露。
辐射暴露应控制在低于监管机构设定的处方剂量限制水平。

/ Optimisation – Occupational

<!> ATTENTION

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

TIME: ↘ time = ↘ exposure
时间： 时间 = 暴露

Stay near radiological equipment for as short a time as possible
在放射设备附近停留尽可能短的时间

SHIELDING: ↗ shielding = ↘ exposure
屏蔽： 屏蔽 = 暴露

Always use shielding
始终使用屏蔽

DISTANCE: ↗ distance = ↘ exposure
距离： 距离 = 暴露

Stay as far as possible from the source of exposure (sometimes the source can be the patient)
尽可能远离暴露源（有时暴露源可能是患者）

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**

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

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章节大纲：

/ 优化 - 职业

<!> 注意

对职业暴露人员的辐射防护有 3 条基本规则：

进一步的辐射防护措施包括：

- / 持续监测工作场所的辐射水平
- / 使用个人剂量计跟踪个人暴露情况，并对接触辐射的人员定期进行健康监测
- / 有关辐射风险、安全程序和防护设备正确使用的充分培训，以及有关最佳实践和法规或技术变更的持续教育

/ 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.

* see next page

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

CHAPTER OUTLINE:

/ **放射生物学原理和辐射防护**

章节大纲：

/ 优化 - 患者

<!> 注意

患者辐射暴露优化措施的非详尽列表：

- / 尽可能减少采集/投影/影像的数量。
- / 准直。
- / 合理的患者定位（后前位 vs 前后位、定心等）。
- / 方案优化。
- / 实施现代剂量降低技术，如自动曝光控制和基于器官的管电流调制。
- / 使用选择性滤波，设置适当的曝光参数。
- / 迭代重建。
- / 确立和监测诊断参考水平 (DRL)*。
- / 与患者沟通，鼓励患者配合。

*见下页

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

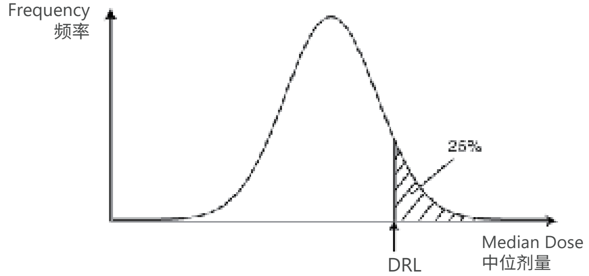
/ anatomical region specific

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.

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/ **放射生物学原理和辐射防护**

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章节大纲：

诊断参考水平 (DRL) 是确保医学影像检查中患者安全的重要部分。DRL 通过为常用诊断程序中使用的典型剂量提供基准，帮助避免不必要的辐射暴露，鼓励不断优化成像技术实践。

DRL 包括：

/ 在一组患者中通用

/ 特定模式

/ 特定解剖区域

DRL 并非：

/ 良好实践与不良实践之间的界限

/ 剂量限制

/ 设计用于个体患者和个体检查

/ **全国 DRL (NDRL)** 通过全国调查设定，采用中位剂量分布的**第三四分位数值**。

/ **当地 DRLs (LDRL)** 采用中位剂量分布的第三四分位数值，对应于机构/机构组织的当地实践；每个影像学中心应建立自己的 **LDRLs** 或"**诊断标准剂量 - DSD**"。

/ 应对 DSD 与 NDRL 进行**比较**，必要时实施纠正措施。

/ 如果超过 NDRL，应进行分析。

/ DRL（NDRL 和 LDRL）的修订是一个迭代过程。

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

Gonad and Patients Shielding Group (GAPS): European Consensus

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章节大纲：

目前，辐射安全和影像学检查所涉及的主要机构已经达成共识。

性腺与患者屏蔽防护组 (GAPS)：欧洲共识

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.

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为普及所述共识，这一组织的工作成果和相关建议已经在不同的科学期刊上发表。

<∞> 参考文献

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/**表 1** 共识声明的依据

Rationale/依据	**Consensus Recommendation/共识建议**	**Symbol/符号**
Evidence that using patient contact shielding is beneficial and effective 使用患者接触屏蔽有益且有效的证据	'Should use shielding' "应使用屏蔽"	
General agreement favours usefulness of patient contact shielding in some circum - stances 普遍共识支持患者接触防护罩在某些情况下有用 - 立场	'May use shielding' "可使用屏蔽"	
Evidence or general agreement not to use patient contact shielding 不使用患者接触屏蔽的证据或普遍共识	'Not recommended to use shielding' "不建议使用屏蔽"	

<∞> 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.

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/ **放射生物学** 原理和 **辐射防护**

章节大纲：

<!> 注意

关于患者屏蔽防护的共识如下：

<∞> 参考文献

表格来源：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:

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

Application 应用	Imaging modality 成像模式	Inside or outside FOV FOV 内部或外部	Recommendation 建议	Symbol 符号
Thyroid contact shielding 甲状腺接触屏蔽	Radiogra - phy, Mam - mography, Fluoroscopy, CT X 线摄影、乳腺 X 线摄影、荧光透视、CT	Outside 外部	'Not recommended to use shielding' "不建议使用屏蔽"	
Thyroid contact shielding 甲状腺接触屏蔽	Dental intraoral and cephalomet - ric radiogra - phy 口内和头颅侧位片	Outside 外部	'May use shielding' "可使用屏蔽"	
Thyroid contact shielding 甲状腺接触屏蔽	CBCT	Outside 外部	'May use shielding' "可使用屏蔽"	
Thyroid contact shielding 甲状腺接触屏蔽	All X - ray (except Cephal.) 所有 X 光检查（头颅除外）	Inside 内部	'Not recommended to use shielding' "不建议使用屏蔽"	
Thyroid contact shielding 甲状腺接触屏蔽	Cepha - lometric radiography 头颅侧位片	Inside 内部	'May use shielding' "可使用屏蔽"	
Embryo / Fetal contact shielding 胚胎/胎儿接触屏蔽	All X - ray 所有 X 线检查	Inside 内部	'Not recommended to use shielding' "不建议使用屏蔽"	
Embryo / Fetal contact shielding 胚胎/胎儿接触屏蔽	Radiogra - phy, Mam - mography, Fluoroscopy, Dental Radi - ography, CT X 线摄影、乳腺 X 线摄影、荧光透视、牙科 X 线摄影、CT	Outside 外部	'Not recommended to use shielding' "不建议使用屏蔽"	
Breast contact shielding 乳房接触屏蔽	All X - ray 所有 X 线检查	Both 两者	'Not recommended to use shielding' "不建议使用屏蔽"	
Eye lens contact shielding 眼晶状体接触屏蔽	All X - ray 所有 X 线检查	Both 两者	'Not recommended to use shielding' "不建议使用屏蔽"	
Male and female gonad contact shielding 男性和女性性腺接触屏蔽	All X - ray 所有 X 线检查	Both 两者	'Not recommended to use shielding' "不建议使用屏蔽"	

<∞> 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.

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章节大纲：

<!> 注意

关于患者屏蔽防护的共识如下：

对于大多数影像学检查方法，**通常不建议进行患者屏蔽防护**，但在某些特定情况下可以使用。

<∞> 参考文献

表格来源：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.

/ 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:

章节大纲：

/ 限制

<!> 注意

限制原则包括在国家层面的法规中确立限制剂量值。暴露人员分为三类：

职业暴露工作人员

20 mSv/年（全身）
20 mSv/年（眼晶状体）
500 mSv/年（四肢）

公众 + 职业暴露孕妇

1 mSv/年

患者

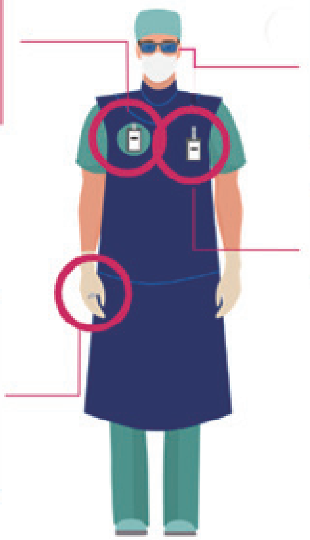
无剂量限制
适用正当性原则。

/ 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**.
全身剂量计置于防护服下方的胸部水平（或怀孕工人的腹部水平）。用于估计**有效剂量**。



The dosimeter placed at the eyes level provides an estimation the **dose to the eye lens**.
置于眼睛处的剂量计可估计**眼晶状体剂量**。

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.
将肢体剂量计放在手指上，以估计**手部剂量**。通常在进行介入手术或使用开放源（即核医学）进行活动时需要。用于估计**肢体剂量**。

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.
防护服剂量计可估计**防护服外器官的剂量**。根据当地法律，也可用于**更准确地估计**有效剂量甚至眼晶状体剂量。

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

CHAPTER OUTLINE:

/ **放射生物学原理和辐射防护**

章节大纲：

/ 限制 - 职业暴露人员

<!> 注意

职业暴露工人需要根据作业类型佩戴不同的剂量计。

/ 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:

章节大纲：

/ 核心要点

<!> 注意

- / 电离辐射有不同类型。
- / 吸收剂量 (D) 定义为电离辐射作用于受照物质每单位质量时释放的能量，是唯一可测量的剂量。
- / 当量剂量 (H) 为吸收剂量乘以辐射权重因子。
- / 有效剂量 (E) 是各器官的当量剂量与其权重因子的乘积之和。
- / 辐射可直接或间接损伤细胞。
- / 电离辐射存在两种效应特征：确定性和随机性。
- / 线性非阈值模型是最常用的估计电离辐射随机健康效应的模型。
- / 我们都暴露于自然辐射中。
- / 开具放射学检查或操作处方的医生和执行这些操作的医生负责应用正当性原则。
- / 根据 ALARA 原则进行优化。
- / 面临职业暴露的工人和公众都有剂量限制，但患者没有。对于患者而言，适用正当性原则和优化原则。

/ 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-ionising-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.
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章节大纲：

/ 参考文献

/ 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-Ionising-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

Test Your Knowledge

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

放射生物学
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CHAPTER OUTLINE:

章节大纲：

知识测试

/ 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).

CHAPTER OUTLINE:

章节大纲：

/ 知识测试

<?> 问题

1 辐射后，细胞的DNA 可以（可能有多个答案）：

- ☐ 不能自行修复，导致细胞死亡。
- ☐ 修补所有破损，无任何后效。
- ☐ 通过出错（突变）来自我修复。

/ 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).

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

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/ 知识测试

<?> 回答

1 辐射后，细胞的DNA 可以（可能有多个答案）：

- 不能自行修复，导致细胞死亡。
- 修补所有破损，无任何后效。
- 通过出错（突变）来自我修复。

/ Test Your Knowledge

<?> QUESTION

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

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

/ 知识测试

<?> 问题

2 确定性效应出现的一般阈值为：

- ☐ 0.5 Gy
- ☐ 20 mSv
- ☐ 无阈值

/ Test Your Knowledge

<?> ANSWER

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

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

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

CHAPTER OUTLINE:

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章节大纲：

/ 知识测试

<?> 回答

2 确定性效应出现的一般阈值为：

- ■ 0.5 Gy
- ☐ 20 mSv
- ☐ 无阈值

/ 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.

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章节大纲：

/ 知识测试

<?> 问题

3 随机性效应的含义（可能有多个答案）：

- ☐ 胎儿中每希沃特癌症发生风险增加 10% 至 20%。
- ☐ 成人中每希沃特癌症发生风险增加 5%。
- ☐ 超过阈值剂量时发生的组织效应。

/ 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.

/ 知识测试

<?> 回答

3 随机性效应的含义（可能有多个答案）：

- ■ 胎儿中每希沃特癌症发生风险增加 10% 至 20%。
- ■ 成人中每希沃特癌症发生风险增加 5%。
- ☐ 超过阈值剂量时发生的组织效应。

/ 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.

CHAPTER OUTLINE:

章节大纲：

/ 知识测试

<?> 问题

4 皮肤受到单次 2 Gy 的辐射在短期内可导致：

- ☐ 无反应。
- ☐ 组织坏死。
- ☐ 一过性红斑。

/ 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.

/ 知识测试

<?> 回答

4 皮肤受到单次 2 Gy 的辐射在短期内可导致：

- ☐ 无反应。
- ☐ 组织坏死。
- ■ 一过性红斑。

/ Test Your Knowledge

<?> QUESTION

5 The fundamental principles of radiation protection are:

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

CHAPTER OUTLINE:

章节大纲：

/ 知识测试

<?> 问题

5 辐射防护的基本原则是：

- ☐ 时间、屏蔽、距离。
- ☐ 正当性、优化和限制。
- ☐ 正当性、优化、限制和培训。

/ Test Your Knowledge

<?> ANSWER

5 The fundamental principles of radiation protection are:

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

CHAPTER OUTLINE:

章节大纲：

/ 知识测试

<?> 回答

5 辐射防护的基本原则是：

- ☐ 时间、屏蔽、距离。
- ■ 正当性、优化和限制。
- ☐ 正当性、优化、限制和培训。

/ 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.

CHAPTER OUTLINE:

章节大纲：

/ 知识测试

<?> 问题

6 诊断参考水平：

- ☐ 它们代表患者剂量的参考上限。
- ☐ 与解剖区域无关。
- ☐ 是优化患者剂量的工具。
- ☐ 如果患者剂量超过限值，则表明是不良实践。

/ Test Your Knowledge

<?> ANSWER

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.

CHAPTER OUTLINE:

章节大纲：

/ 知识测试

<?> 回答

6 诊断参考水平：

- ☐ 它们代表患者剂量的参考上限。
- ☐ 与解剖区域无关。
- ■ 是优化患者剂量的工具。
- ☐ 如果患者剂量超过限值，则表明是不良实践。

/ 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.

CHAPTER OUTLINE:

章节大纲：

/ 知识测试

<?> 问题

7 以下关于辐射暴露限值的表述正确的是?

- ☐ 对患者的辐射剂量没有限制。
- ☐ 职业暴露人员的限值为每月 1 mSv。
- ☐ 职业暴露人员的限值为每年 20 mSv。
- ☐ 对公众的辐射剂量没有限制。

/ Test Your Knowledge

<?> ANSWER

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CHAPTER OUTLINE:

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<?> 回答

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