



Radiation Safety
辐射安全



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Basic Definition of Radiation

辐射基本定义

What is Radiation?
什么是辐射?

◆ Waves or particles that carry energy. It can be classified into:

辐射：携带能量的波或粒子。它被分为：

- Ionizing Radiation

电离辐射

- Non-ionizing Radiation

非电离辐射

Basic Definition of Radiation

辐射基本定义

Ionizing Radiation

电离辐射

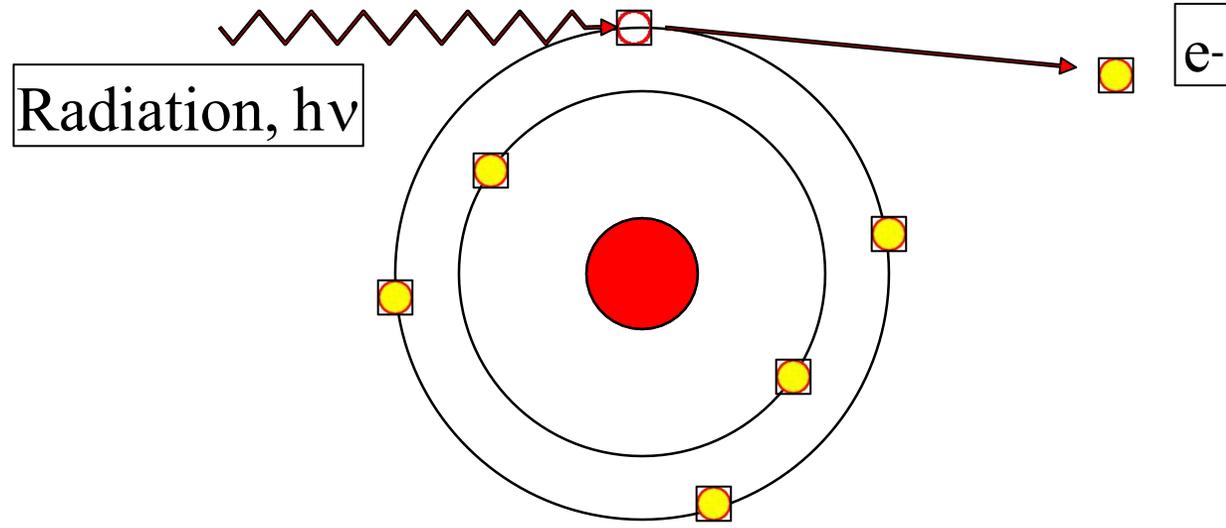
- ◆ Particles or photons **with sufficient energy** to produce ions in the medium.

具有**足够能量**在介质中产生离子的粒子或光子。



Basic Definition of Radiation 辐射基本定义

Ionizing Radiation 电离辐射



- ◆ Ionization is the removal of an electron from an atom or an ion, resulting in an ion pair.
电离是从原子或离子中移除一个电子，从而形成一个离子对。
- ◆ Ionization is the primary cause of radiation- induced biological damage.
电离是辐射诱导生物损伤的主要原因。

Being exposed to natural (background) radiation is a normal part of life. There's no need to worry due to its low dose rate.

暴露于天然辐射源（本底值）中是生活的常态。因为该辐射的剂量率低，无需过度担心。

Source of Ionizing Radiation
电离辐射来源

Natural Source
天然源
82%

Man-made source
人工源
18%

Cosmic Rays
宇宙射线

Soil, Rock, Building
土壤, 岩石, 建筑

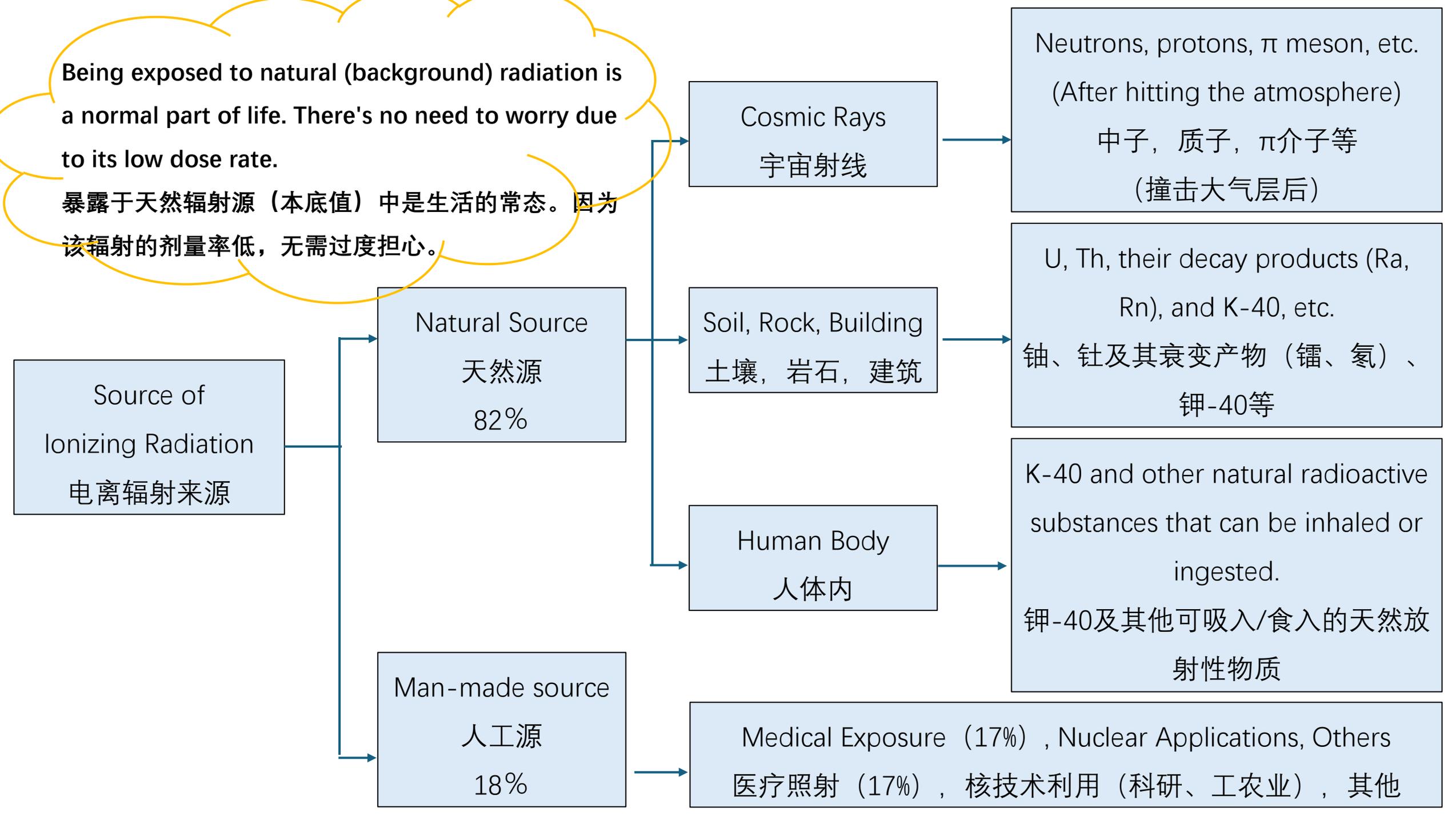
Human Body
人体内

Medical Exposure (17%), Nuclear Applications, Others
医疗照射 (17%), 核技术利用 (科研、工农业), 其他

Neutrons, protons, π meson, etc.
(After hitting the atmosphere)
中子, 质子, π 介子等
(撞击大气层后)

U, Th, their decay products (Ra, Rn), and K-40, etc.
铀、钍及其衰变产物 (镭、氡)、钾-40等

K-40 and other natural radioactive substances that can be inhaled or ingested.
钾-40及其他可吸入/食入的天然放射性物质



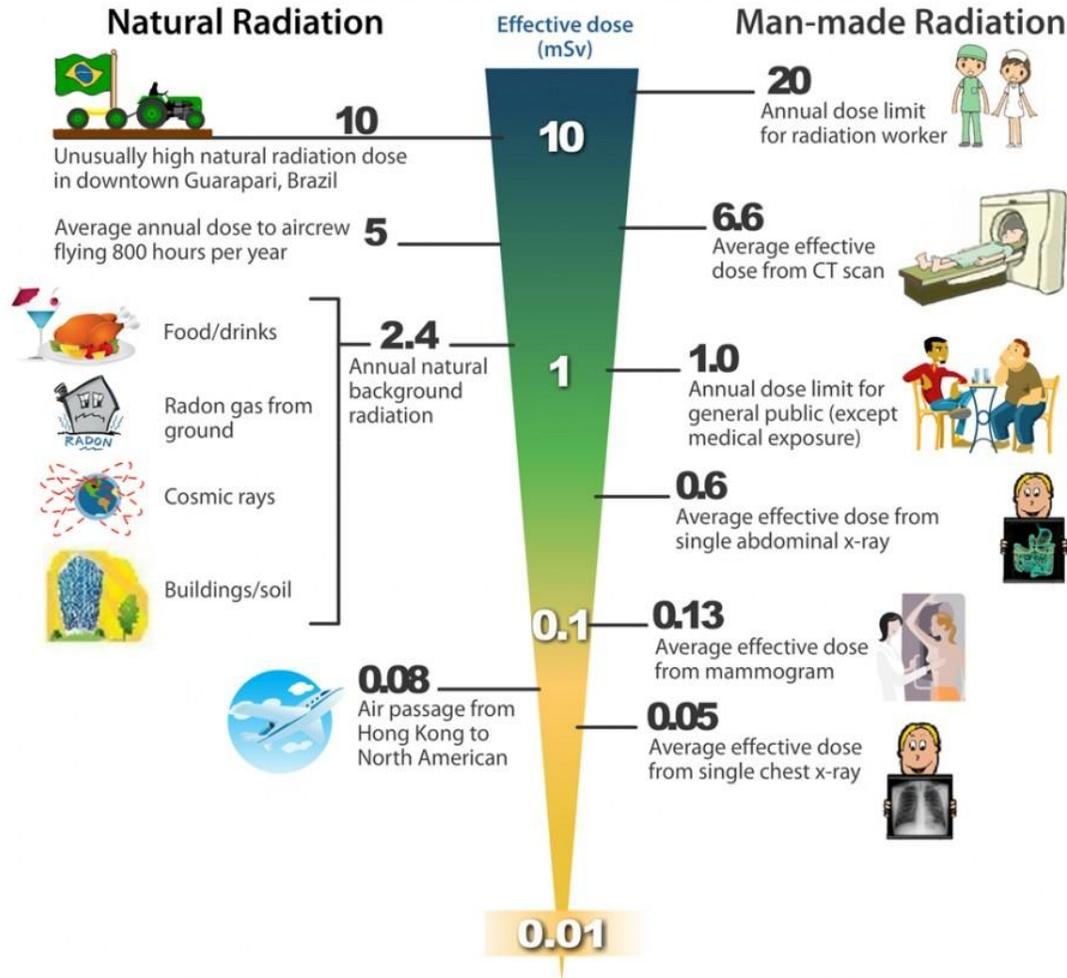
Basic Definition of Radiation

辐射基本定义

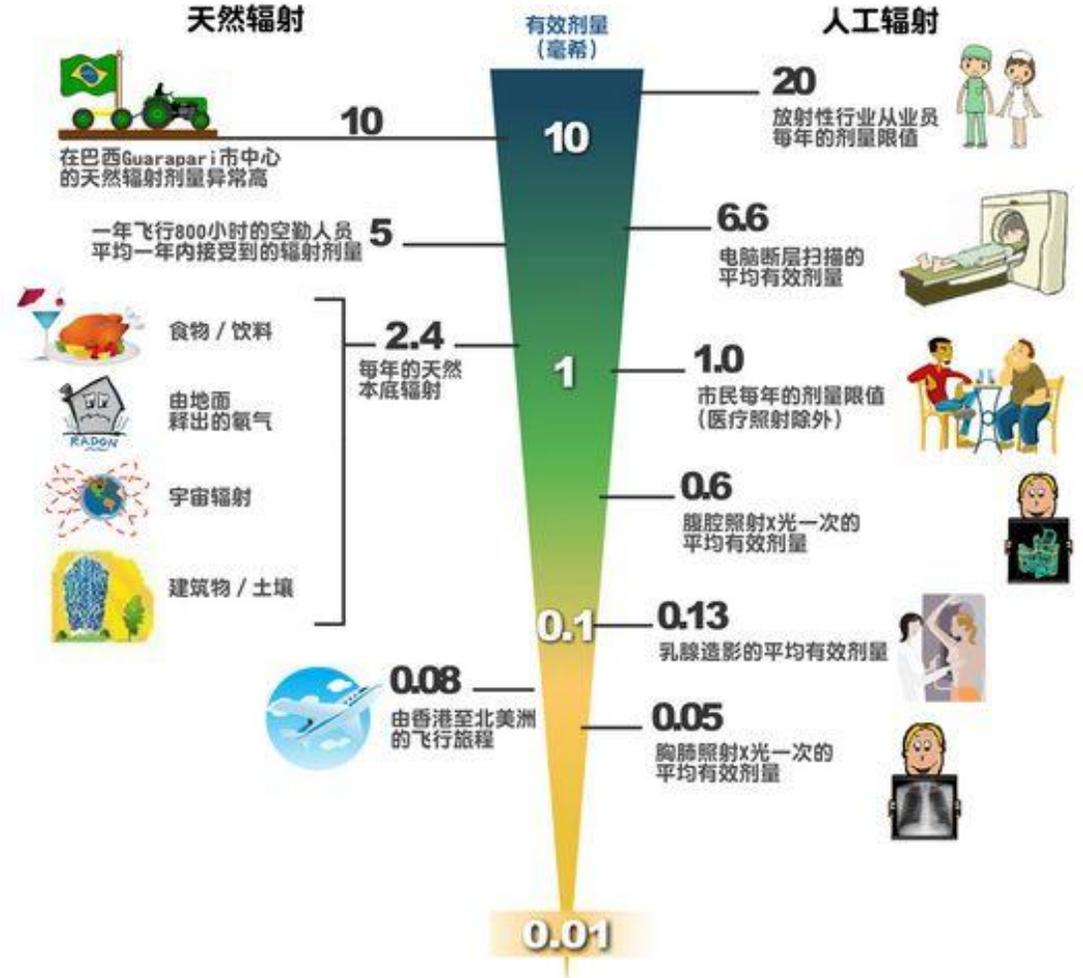
Radiation in Daily Life

日常生活中的辐射

Radiation in Daily Life



日常生活中的辐射



Basic Definition of Radiation

辐射基本定义

Non-ionizing Radiation

非电离辐射

- ◆ Non-ionizing Radiation that **does not have sufficient energy** to ionize an atom.

非电离辐射是指其**能量不足以**使原子发生电离的辐射。

- e.g., Radar waves, microwaves and UV light.

例如：雷达，微波和紫外

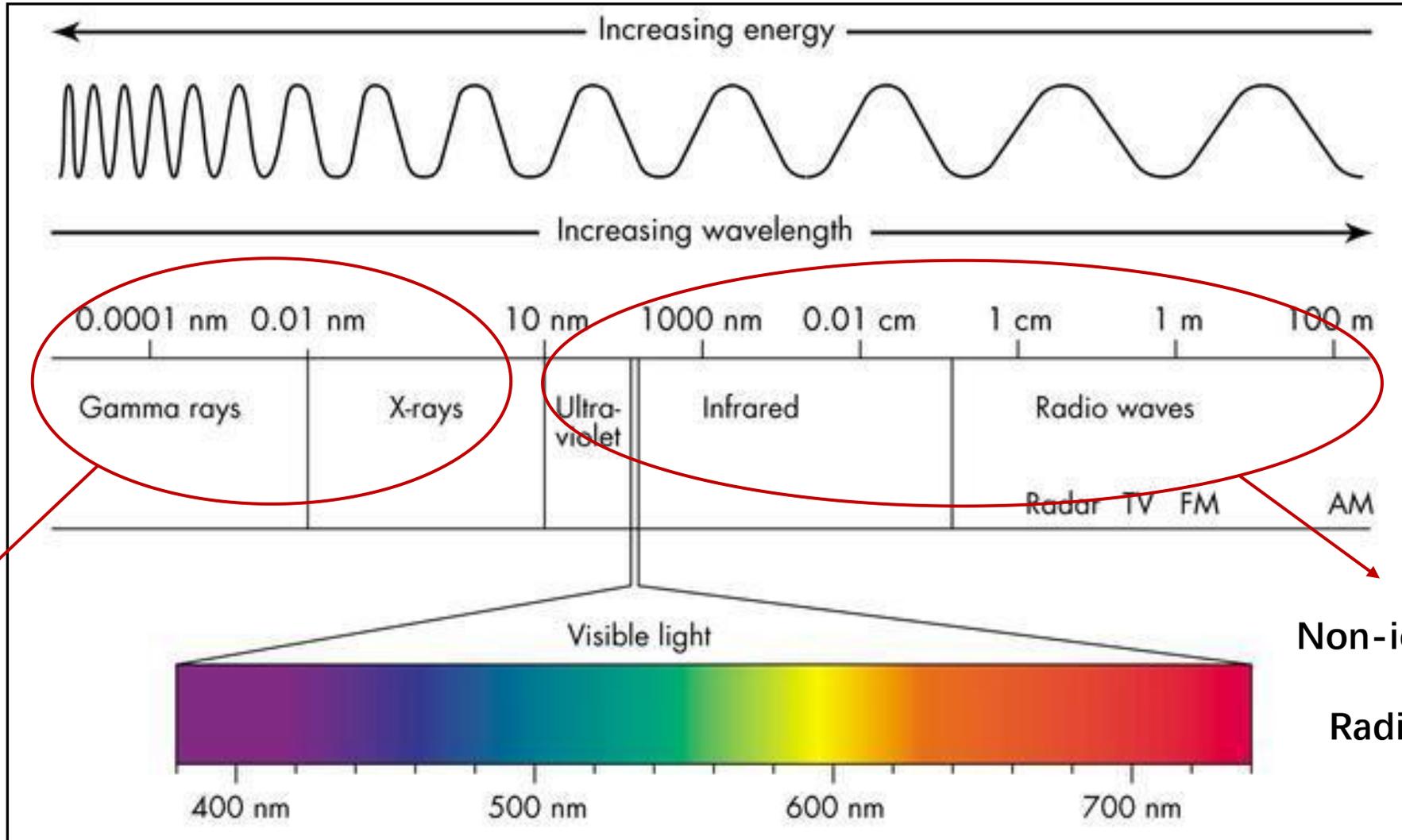


Basic Definition of Radiation 辐射基本定义

Electromagnetic Spectrum 电磁波谱

The Relationship: Frequency vs. Wavelength

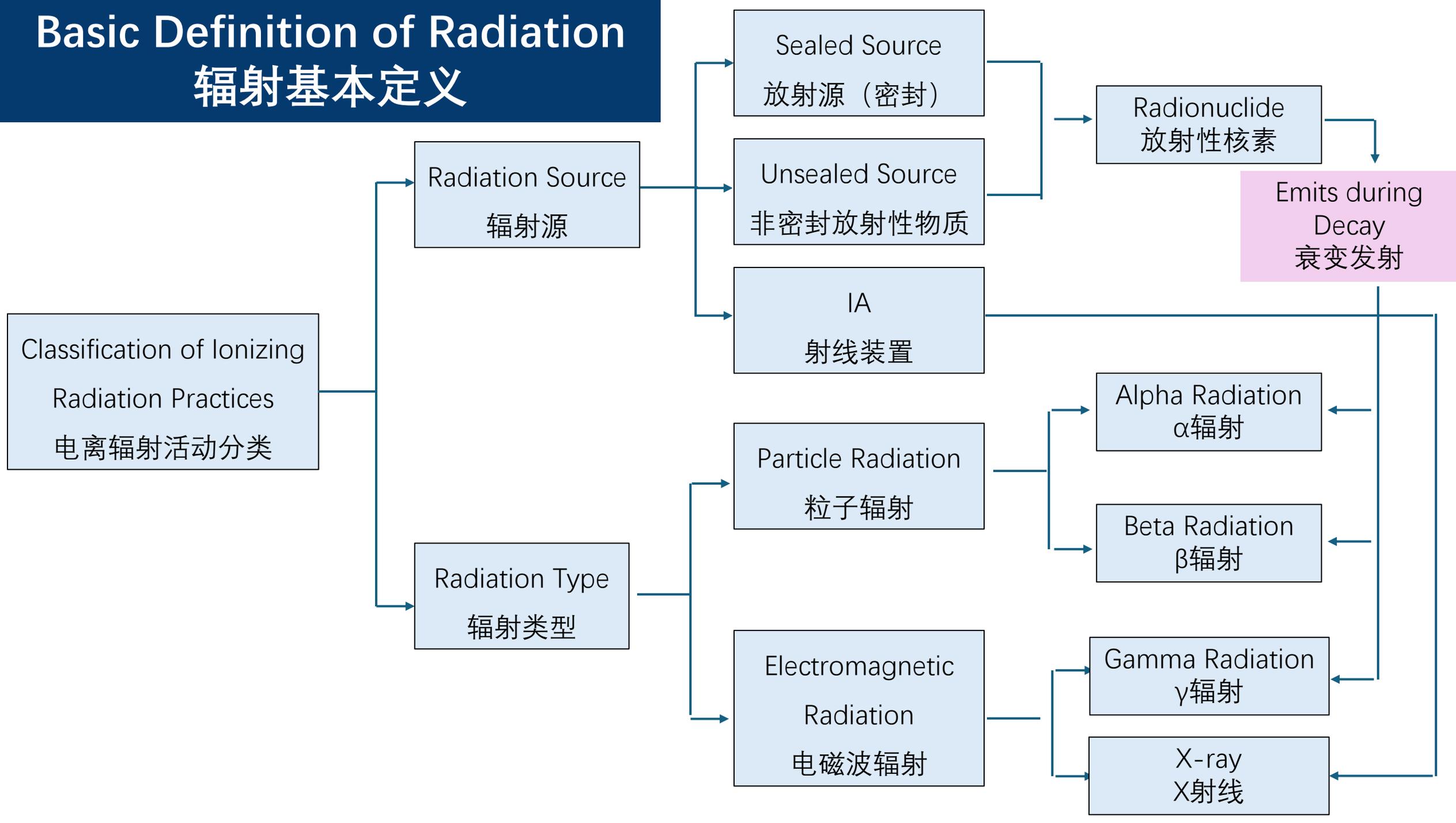
$$\lambda f = c = 3 \times 10^8 \text{ m/s}$$



Ionizing
Radiation

Non-ionizing
Radiation

Basic Definition of Radiation 辐射基本定义





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Type of Ionizing Radiation 电离辐射类型

Alpha particles
 α 粒子

- ◆ He^{2+} (氦原子核,带两个正电荷)
- ◆ A (质量数) =4, heavy mass (重质量)
- ◆ **short ranges:** 1 to 2 inches in air, 40 to 70 μm in tissue (cannot penetrate the dead layer of skin)

射程短: 它们在空气中的射程很短: 约为1至2英寸 (约2.5至5厘米), 在组织中的射程为40至70微米 (无法穿透皮肤的角质层)。

- ◆ **Alpha can be stopped by even a piece of paper.**

α 能被一张纸阻挡。



Type of Ionizing Radiation

电离辐射类型

Beta particles β粒子

- ◆ Beta particles are electrons emitted from the nucleus, so they carry a negative charge (-1).

β粒子是从原子核中释放出的电子，因此它们带有负电荷（-1）。

- ◆ longer ranges than α : 10-20 feet in air, several mm in human tissue.

射程比 α 更长：在空气中为10-20英尺（约3-6米），在人体组织中可达数毫米。

- ◆ Half inch of plastic or plexiglass will stop most beta particles.

半英寸（约1.27厘米）厚的塑料或有机玻璃即可阻挡大多数β粒子

Type of Ionizing Radiation

电离辐射类型

Gamma and X-ray
 γ 和 X射线

Feature特性	Description	描述
Origin起源	Gamma: Atomic nucleus X-ray: Electron shell	γ 射线: 原子核内 X射线: 核外电子层
Nature本质	Photons (Electromagnetic radiation) no charge	均为光子 (电磁辐射) 不带电
Penetration穿透力	Very long range in air (Several hundred feet) Can penetrate the human body	空气中射程极长 (数百米) 可穿透人体
Shielding屏蔽	High-Z materials (e.g., Lead)	高原子序数材料 (如铅)



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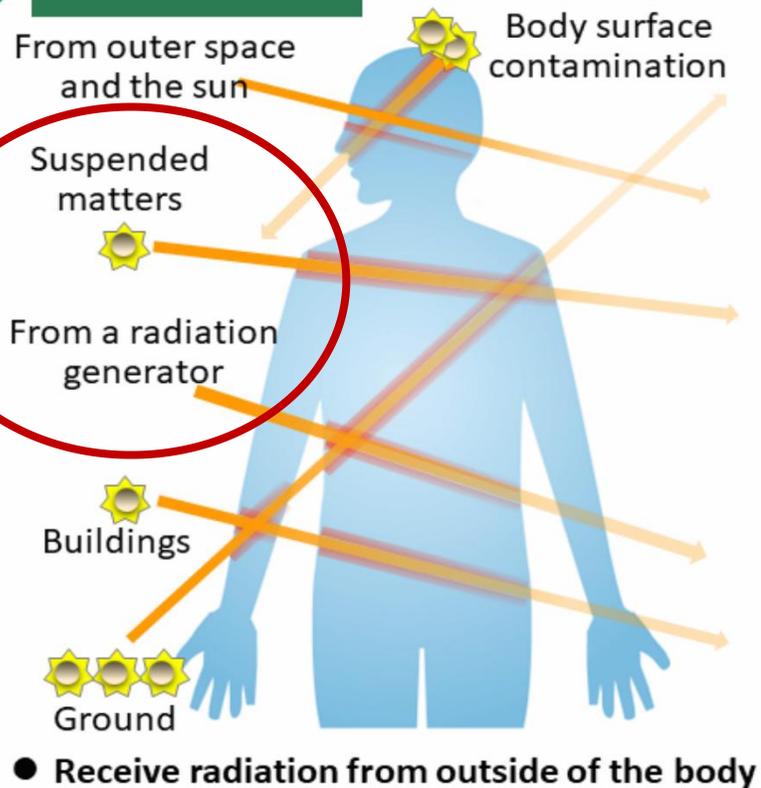
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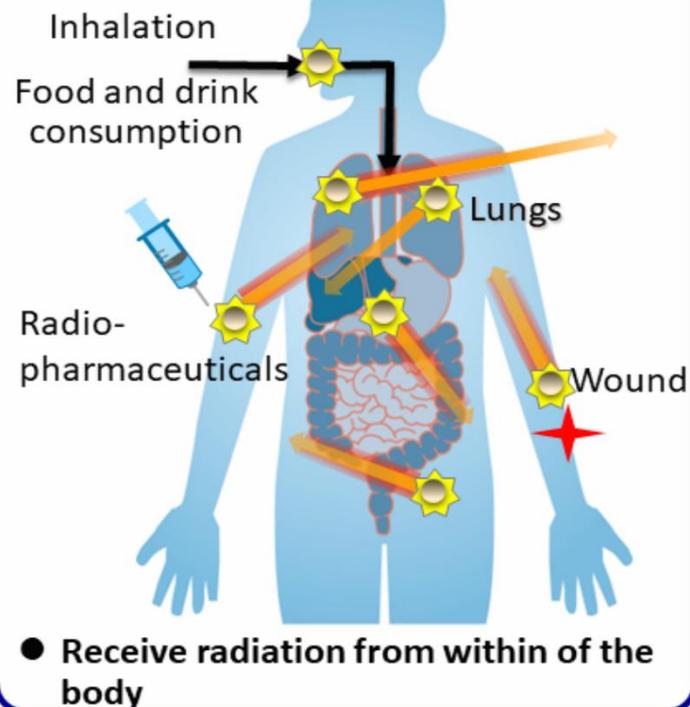
Exposure Routes

Internal and External Exposure

External exposure



Internal exposure



The body is equally exposed to radiation in both cases.

Radioactive materials

- ◆ Due to its short range in tissue, the primary hazard of alpha is internal exposure.

由于 α 在组织中的射程极短，一般仅考虑内照射风险

External Hazard外照射风险:

$$n > \gamma / X > \beta > \alpha$$

Internal Hazard内照射风险:

$$\alpha > \beta > \gamma / X$$

- ◆ Each organ of the human body is made up of specialized cells. **Ionizing radiation can potentially affect the normal functioning of these cells.**

人体的每个器官都由特化的细胞构成。 **电离辐射可能会影响这些细胞的正常功能。**

- ◆ Somatic effects: effects on the body of the individual receiving radiation, **e.g., mutation of cells leading to cancer.**

躯体效应： 指辐射对受照射个体身体产生的影响， **例如， 细胞突变导致癌症。**

- ◆ Genetic effects: effects on chromosomes of reproductive cells, **may be inherited.**

遗传效应： 指对生殖细胞（精子和卵子）染色体的影响， **这种效应可能会遗传给后代。**

Exposure Hazard and Control 照射风险和控制

Incident sharing 事故案例

- ◆ On November 21, 2021, a company in Dongguan purchased three portable X-ray machines from a supplier, with neither party holding a 辐射安全许可证. The unshielded equipment, lack of safety procedures and PPE led to two workers' suffering from radiation injuries, with their hands showing blackened and ulcerated .

2021年11月21日，东莞某无《辐射安全许可证》的公司，从同样无证的销售方购买了3台便携式X射线机。因设备无屏蔽，公司无安全操作规程，未配置防护用品，导致2名职工受到放射性损伤，手部出现发黑溃烂。



Exposure Hazard and Control

照射风险和控制

Incident sharing 事故案例

- ◆ In 1987, scrap collectors in Goiânia, Brazil, took home and dismantled a teletherapy unit containing a 51TBq CS-137 left behind after a hospital relocation, causing radioactive powder to leak. The collectors developed **vomiting and hand swelling**. Then they sold the assembly to a scrap dealer. Seeing the powder glow in the dark, the dealer mistook it for treasure, invited family and friends to view it, and distributed rice-sized particles to children to play with. Days later, multiple people exposed to the radiation developed **gastrointestinal symptoms**.

1987年，巴西戈亚尼亚一家医院搬迁后遗留的远程治疗机（内含51TBq的Cs-137放射源）被拾荒者带回家拆解导致放射性粉末泄漏，拾荒者**出现呕吐、手肿胀等症状**。随后放射源组件被作为废品卖给废品收购者，废品收购者见罐内粉末在黑暗中发光，误以为珍宝，邀亲友来家观看。米粒大小的粉末被分发给多户，供儿童玩耍。多日后，多名接触者因辐射陆续出现**胃肠道症状**。



◆ ALARA = As Low As Reasonably Achievable

合理可行尽量低

- Reduce [time](#) near radionuclide
减少在辐射场中停留的时间
- Increase [distance](#) from radionuclide
尽可能远离辐射源
- Add appropriate [shielding](#)
利用材料吸收和减弱辐射

Exposure Hazard and Control

照射风险和控制

ALARA Approach - Time
ALARA原则 - 时间

- ◆ Pre-plan and discuss the task thoroughly prior to enter the radiation work area.

在进入辐射工作区域之前，应事先详细规划并讨论相关任务。

- ◆ Perform as much non-radiation work as possible outside the designated areas of radiation work.

尽可能在辐射作业区域之外开展非辐射性工作。

- ◆ Have all necessary tools before entering the area.

在进入该区域之前，请确保携带齐全所有必要的工具。

- ◆ Increase Work efficiently.

提高工作效率



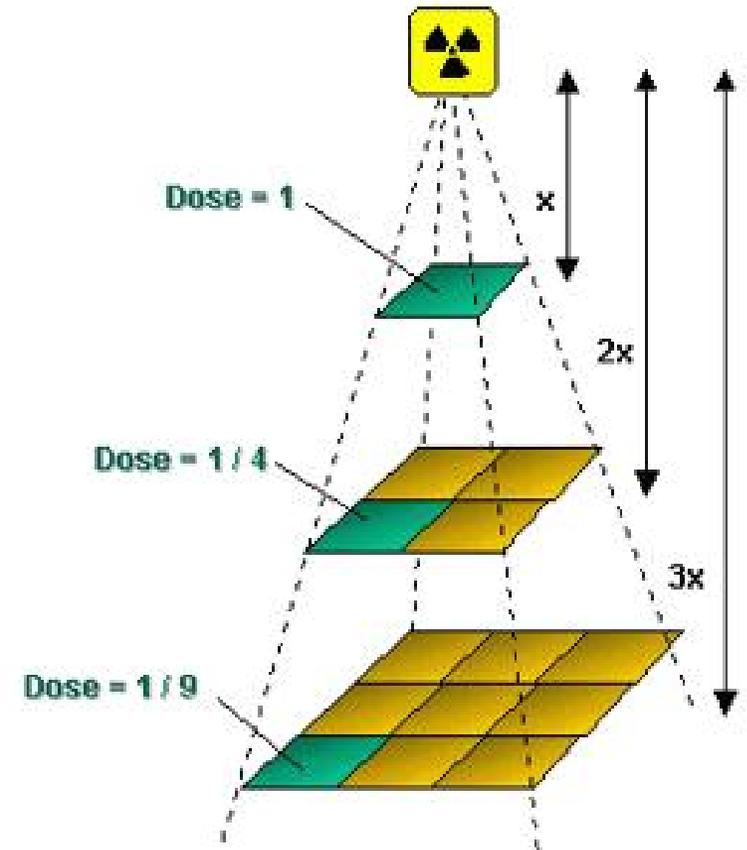
Exposure Hazard and Control 照射风险和控制

ALARA Approach - Distance ALARA原则 – 距离

- ◆ For a point source, radiation exposure is reduced by the inverse square of the distance from the source:
当一个辐射源的尺寸相对于距离可以忽略不计时，其辐射暴露水平与距离的平方成反比：

$$\text{Dose (or Dose Rate)} \propto \frac{1}{\text{Distance}^2}$$

- ◆ Stay as far away as possible from the source without hindering work.
在不妨碍工作的情况下，尽量远离辐射源。
- ◆ Use remote handling device when appropriate.
如有可能，进行远程操作

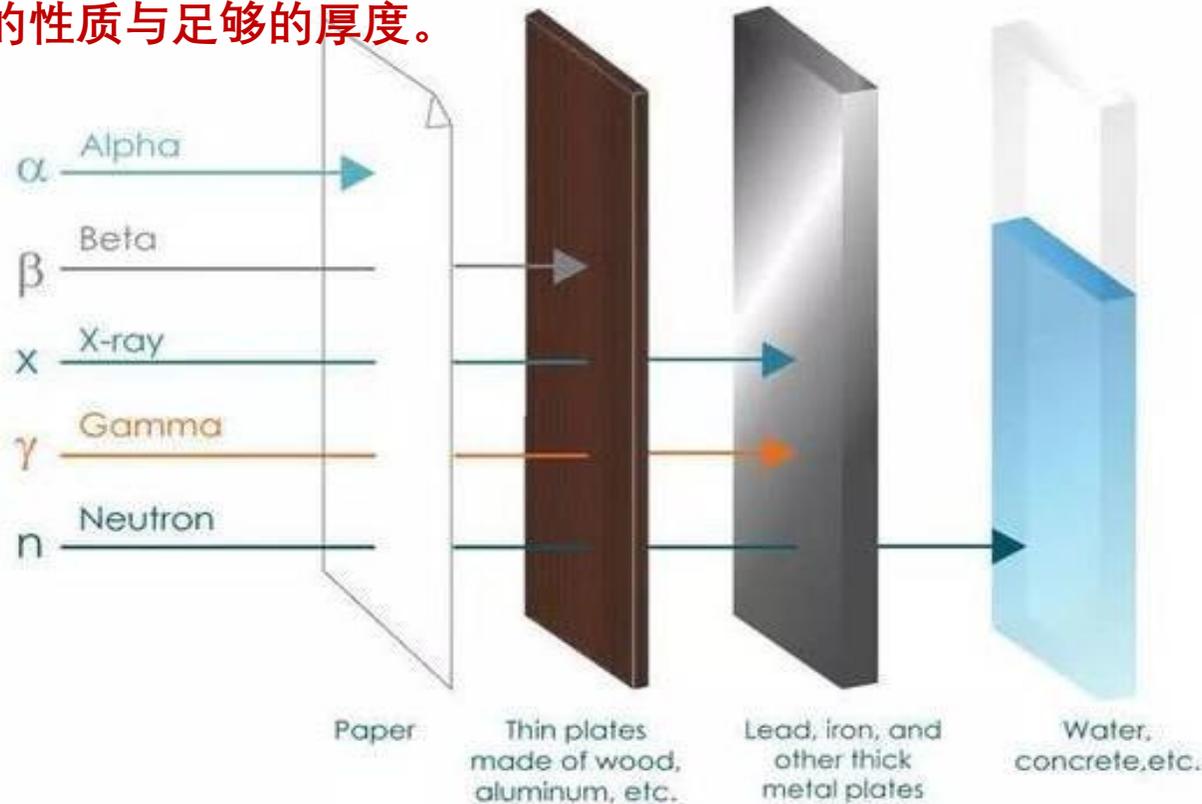


Exposure Hazard and Control 照射风险和控制

ALARA Approach - Shielding ALARA原则 – 屏蔽

- ◆ Shielding effectiveness depends on both the material type and sufficient thickness.

屏蔽效果取决于材料的性质与足够的厚度。

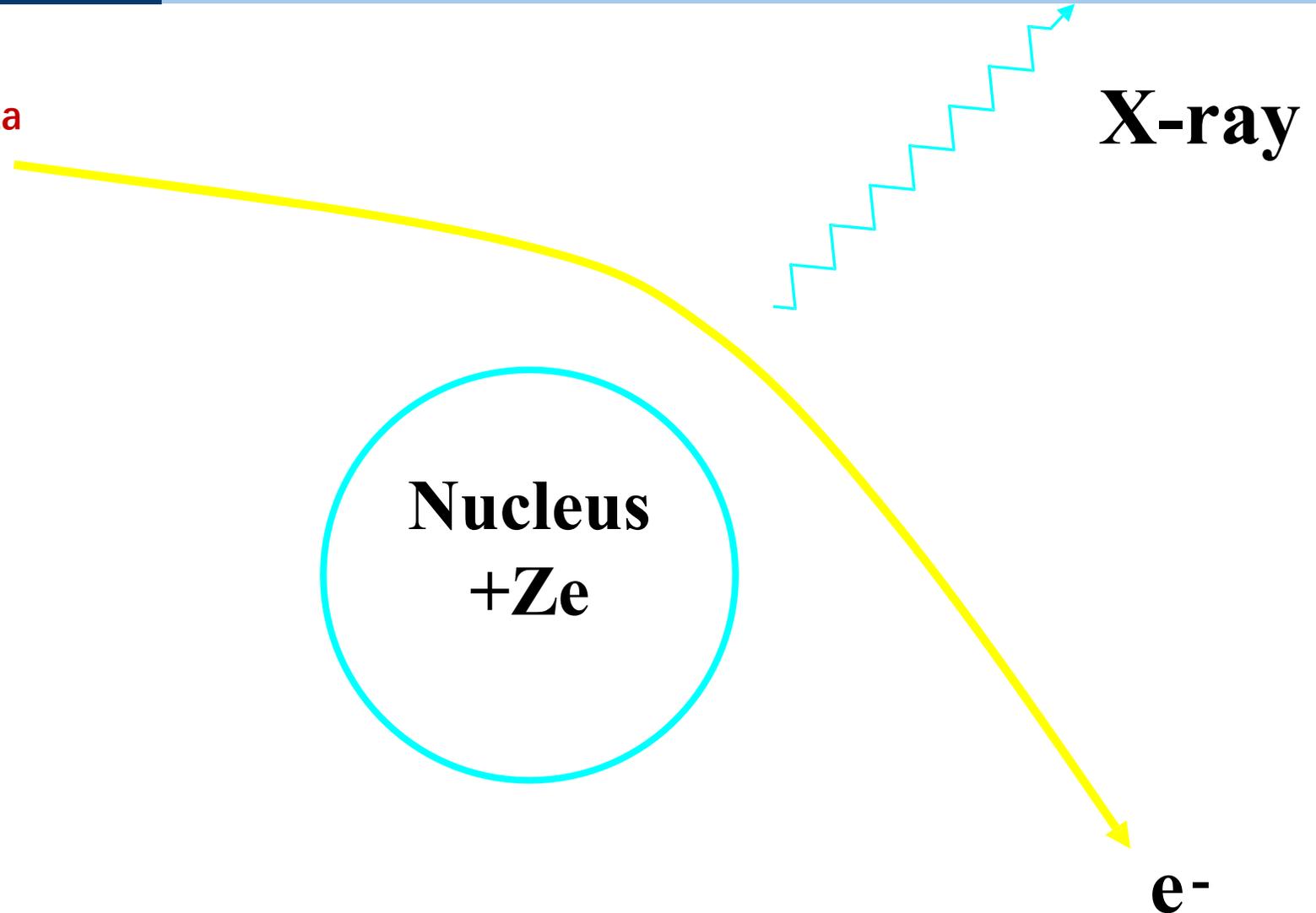


Exposure Hazard and Control 照射风险和控制

Bremsstrahlung
轫致辐射

- ◆ Bremsstrahlung effect occurs when **beta particles or electrons** are slowed down or **stopped by the absorbing medium**, producing x-ray.

轫致辐射效应是指**β粒子或电子**在穿过吸收介质时因**减速或受阻**而产生X射线的现象。



- ◆ Energy loss in bremsstrahlung, or the energy of the x-ray produced, is proportional to the product of the beta energy (E) and the atomic number (Z) of the absorbing medium.

轫致辐射过程中的能量损失，即所产生的X射线能量，与 β 粒子能量 (E) 和吸收介质原子序数 (Z) 的乘积成正比。

- ◆ Therefore, for high-energy β , a dual-layer shielding approach is recommended: first use low- Z materials (e.g., aluminum or plexiglass) to block beta particles and minimize bremsstrahlung production, followed by high- Z materials (e.g., lead) to absorb the secondary bremsstrahlung generated in the first layer.

因此，对于高能 β 粒子，建议采用双层屏蔽策略：首先使用低原子序数材料（如铝或亚克力）阻挡 β 粒子并减少轫致辐射的产生，然后使用高原子序数材料（如铅）吸收在第一层中产生的次级轫致辐射。

- ◆ Shielding effectiveness increases with the thickness.

屏蔽效果会随着厚度的增加而增强。

- ◆ **Half-Value Layer (HVL) is the thickness of any given absorber that will reduce the intensity of beam of radiation to one-half its initial intensity.**

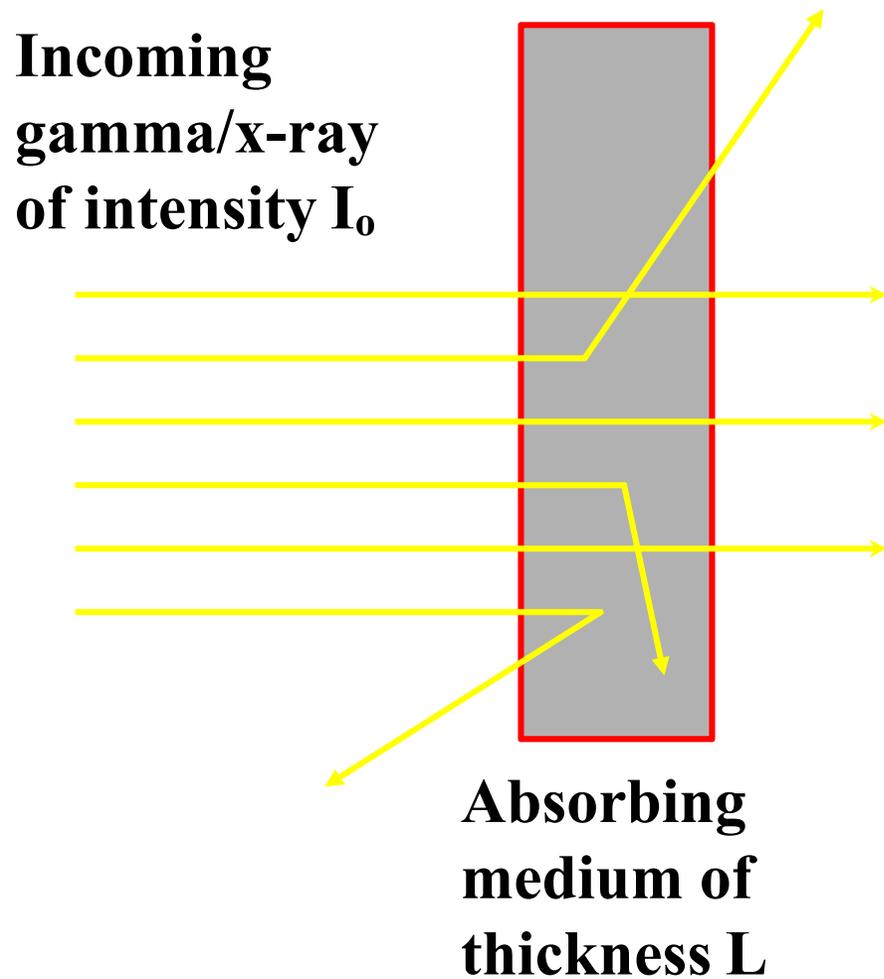
半值层 (HVL) 指的是任何特定吸收材料的厚度，当该厚度达到时，射线的强度会降至初始强度的一半。

- ◆ Seven HVLs will reduce the intensity to less than 1%.

七个HVLs将使辐射强度降低至不足 1%。

Exposure Hazard and Control 照射风险和控制

Shielding against Gamma and X-ray X射线和γ射线的屏蔽



Outgoing gamma/x-ray of intensity I

$$\frac{I}{I_0} = \exp \left[- \frac{L \times \ln 2}{\text{HVL}} \right]$$

when $L = \text{HVL}$, $I = I_0/2$;

when $L = 7 \text{ HVL}$, $I < 0.01 I_0$

Exposure Hazard and Control 照射风险和控制

Shielding against Beta β 的屏蔽

Instructor's Guide

CARBON-14 (C-14)

Carbon-14 is a low-energy beta emitter (about 10 times more energetic than tritium). C-14 is not easily detected with a hand-held survey instrument such as a thin-window G-M (the efficiency is ~ 10%). Monitoring is normally performed by taking a swipe of the area and counting the swipe in a liquid scintillation counter.

1. Maximum energy: 0.156 MeV (the average energy is 0.052 MeV).
2. Maximum range in air: 9 inches (24 cm).
3. IAEA toxicity classification: Medium-low.
4. Physical half-life: 5,730 years.
5. Effective half-life (T_{eff}): 12 days.
6. Critical organ: Whole body and the body fat.
7. Personnel monitoring: Bioassay - urinalysis and/or breath measurements (CO_2), NOT detected with a dosimeter (thermoluminescent dosimeter or film).
8. ALI:
 - 2 mCi (8×10^7 Bq) -labeled organic compounds by inhalation or ingestion.
 - 1.6 Ci (6×10^{10} Bq) CO by inhalation.
 - 200 mCi (7×10^9 Bq) CO_2 by inhalation.
9. Shielding: 3mm of plexiglass (if needed) - thicker plexiglass may be used for rigidity.
10. Special Considerations:

- ◆ Beta particles have a maximum range in materials, determined by their energy.

β 粒子在材料中有最大射程，由其能量决定。

- ◆ Their intensity stays constant until near this range, then drops sharply to zero.

粒子强度即将抵达该距离前基本不变，随后急剧下降至零。

- ◆ therefore, **shielding against beta particles requires a "complete stopping thickness" (the maximum range), not "HVL"**.

因此，屏蔽 β 需要“完全阻挡厚度”（即最大射程），而非“半值层”。

Exposure Hazard and Control 照射风险和控制

Internal exposure control 内照射控制

- ◆ Use a fume hood or glove box for handling unsealed radioactive materials.

使用排风柜或手套箱开展非密封放射性物质的操作。

- ◆ Wear appropriate PPE, e.g., lab coat, gloves, safety glasses.

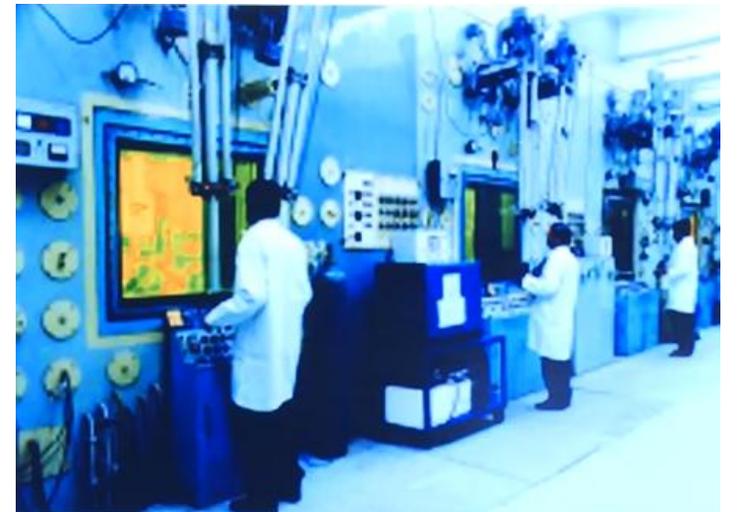
个体防护:如实验服, 手套, 安全眼镜。

- ◆ Eating and drinking are prohibited in radiation work areas.

辐射工作场所禁止饮食。

- ◆ Good ventilation and housekeeping.

良好的通风和整洁的工作场所。





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Measurement of Exposure

辐射暴露测量

Dose 剂量

- ◆ Dose is a key physical quantity used to quantify the level of radiation exposure and assess health risks. It is primarily classified into:

剂量是用于量化辐射照射水平和评估健康风险的关键物理量。它主要分为：

- Absorbed Dose, D:

吸收剂量

- Equivalent Dose, H

当量剂量

- Effective Dose, E

有效剂量

Measurement of Exposure

辐射暴露测量

Absorbed Dose, D
吸收剂量, D

- ◆ The absorbed dose is a measure of energy deposition per unit mass of tissue by ANY type of radiation.

吸收剂量是衡量任何类型的辐射在单位质量组织中沉积能量的物理量。

- ◆ It does not take into account that different types of radiation have different potential effects on the human body.

它没有考虑到，不同类型的辐射对体会产生不同的潜在影响。

- ◆ Conventional unit is “rad”, SI unit is “gray (Gy)” .1 Gy = 100 rad = 1 joule/kg

传统单位是rad，国际单位是Gy。 1 Gy = 100 rad = 1焦耳/千克

Measurement of Exposure 辐射暴露测量

Equivalent Dose, H
当量剂量, H

- ◆ Equivalent Dose takes into account the different potential biological effects to a body tissue due to different type of radiation, even at the same absorbed dose.

即使在吸收剂量相同的情况下，当量剂量也考虑了不同辐射类型对机体组织造成的生物效应的差异。

- ◆ $H_{T,R} = D_{T,R} \cdot W_R$

当量剂量($H_{T,R}$) = 吸收剂量($D_{T,R}$) * 辐射权重因子(W_R).

- ◆ When the radiation field is composed of different types of radiation with different W_R values, the equivalent dose H_T is given by:

$$H_T = \sum_R w_R \cdot D_{T,R}$$

当辐射场是由具有不同 W_R 值的不同类型的辐射所组成时,当量剂量为:

- ◆ Conventional unit is “rem” SI unit is “Sievert (Sv)” 1 Sv = 100 rem

传统单位为“rem”，国际单位为“Sv”。 1Sv = 100 rem

Measurement of Exposure 辐射暴露测量

Equivalent Dose, H
当量剂量, H

Radiation辐射类型

W_R

Gamma/X-ray

光子,所有能量

1

Beta Particles, Electrons

电子及介子, 所有能量

1

Neutrons (all energies)

中子

5-20

Alpha particles

α 、裂变碎片、重核

20

Measurement of Exposure

辐射暴露测量

Effective Dose, E
有效剂量, E

- ◆ Effective dose takes into account of the different biological sensitivities of each organ/tissues to radiation.

有效剂量会考虑到每个器官/组织对辐射的生物敏感度的差异

- ◆ For example 举例说明:

- Highly sensitive organs (e.g., gonads, lungs): Even when exposed to relatively low doses, they are more susceptible to stochastic effects, such as cancer.

敏感度高的器官（如性腺、肺）：即使受到较小的剂量，也更容易引发癌症等随机性效应。

- Less sensitive organs (e.g., skin, bone surface): A significantly higher dose is required to produce a comparable level of risk.

敏感度低的器官（如皮肤、骨表面）：需要更大的剂量才能产生同等级别的风险。

Measurement of Exposure 辐射暴露测量

Effective Dose, E
有效剂量, E

- ◆ Effective Dose, E, of whole body is the summation of tissue equivalent doses, H_T , multiplied by Tissue Weighting Factor, W_T

全身的有效剂量 (E) 等于所有组织 (T) 的当量剂量 (H_T) 与相应组织权重因子 (W_T) 乘积的总和。

$$E = \sum_T H_T \cdot W_T$$

Measurement of Exposure 辐射暴露测量

Effective Dose, E
有效剂量, E

Tissue 组织 / Organ 器官

W_T

Gonads 性腺

0.20

RBM, Colon, Lungs, Stomach (each 0.12)

0.48

红骨髓, 结肠, 肺, 胃 (各0.12)

Bladder, Breast, Liver, Thyroid, Esophagus (each 0.05)

0.25

膀胱, 乳腺, 肝, 甲状腺, 食道 (各0.05)

Skin, Bone Surface (each 0.01)

0.02

皮肤、骨表面 (各0.01)

Remainder 剩余部分

0.05

Whole body 全身

1.00

Measurement of Exposure 辐射暴露测量

Dose Limit 剂量限值

Exposed Group 受照对象	Limit Type 限制类型	Dose Limit 限值标准
Occupational Workers 职业工作人员	Effective Dose 有效剂量	Average per year over 5 consecutive years ≤ 20 mSv 连续5年平均每年 ≤ 20 mSv And in any single year ≤ 50 mSv 且任何一年 ≤ 50 mSv
	Equivalent Dose to the Lens of the Eye 眼晶体当量剂量	Per year ≤ 150 mSv 每年 ≤ 150 mSv
	Equivalent Dose to Skin & Extremities 皮肤和四肢当量剂量	Per year ≤ 500 mSv 每年 ≤ 500 mSv
Members of the Public 公众成员	Effective Dose 有效剂量	Per year ≤ 1 mSv 每年 ≤ 1 mSv
	Equivalent Dose to the Lens of the Eye 眼晶体当量剂量	Per year ≤ 15 mSv 每年 ≤ 15 mSv
	Equivalent Dose to the Skin 皮肤当量剂量	Per year ≤ 50 mSv 每年 ≤ 50 mSv

- ◆ The regulatory authority requires HKUST(GZ) to comply with stricter annual effective dose limits—**5 mSv for radiation workers and 0.25 mSv for the public**—equivalent to one-quarter of the national standard (GB 18871-2002).

根据审管部门规定，香港科技大学（广州）需遵守更严格的年有效剂量限值，即**辐射工作人员 5 mSv/年、公众成员 0.25 mSv/年**，此标准为《电离辐射防护与辐射源安全基本标准》（GB 18871-2002）的四分之一。

Measurement of Exposure 辐射暴露测量

Biological Effects 生物效应

◆ Deterministic Effects

确定性效应

- Generally, a threshold level of dose exists. Severity increases with dose.

通常，存在一个剂量阈值水平。严重程度随剂量增加而增加。

- Once the threshold is exceeded, an individual shows the effect.

一旦超过此阈值，个体就会出现相应的效应。

某些生物效应的剂量阈值

单次照射剂量阈值 /Gy	
眼睛 (X射线照射)	晶体混浊：0.5~2；白内障：5
男性性腺 (睾丸)	精子减少：0.15； 永久性不育：3.5~6
女性性腺 (卵巢)	永久性绝育：2.5~6；
骨髓	造血机能低下：0.5； 致命性再障：1.5

皮肤损伤的程度 /Gy

射线	脱毛	红斑	水泡	溃疡坏死
软X射线	3.0	5.0	7.5	10.0
硬X射线	5.0	7.0	10.0	15.0
γ 射线	7.0	10.0	15.0	20.0
β 射线	4.0~5.0	6.0~7.0	10.0	15.0

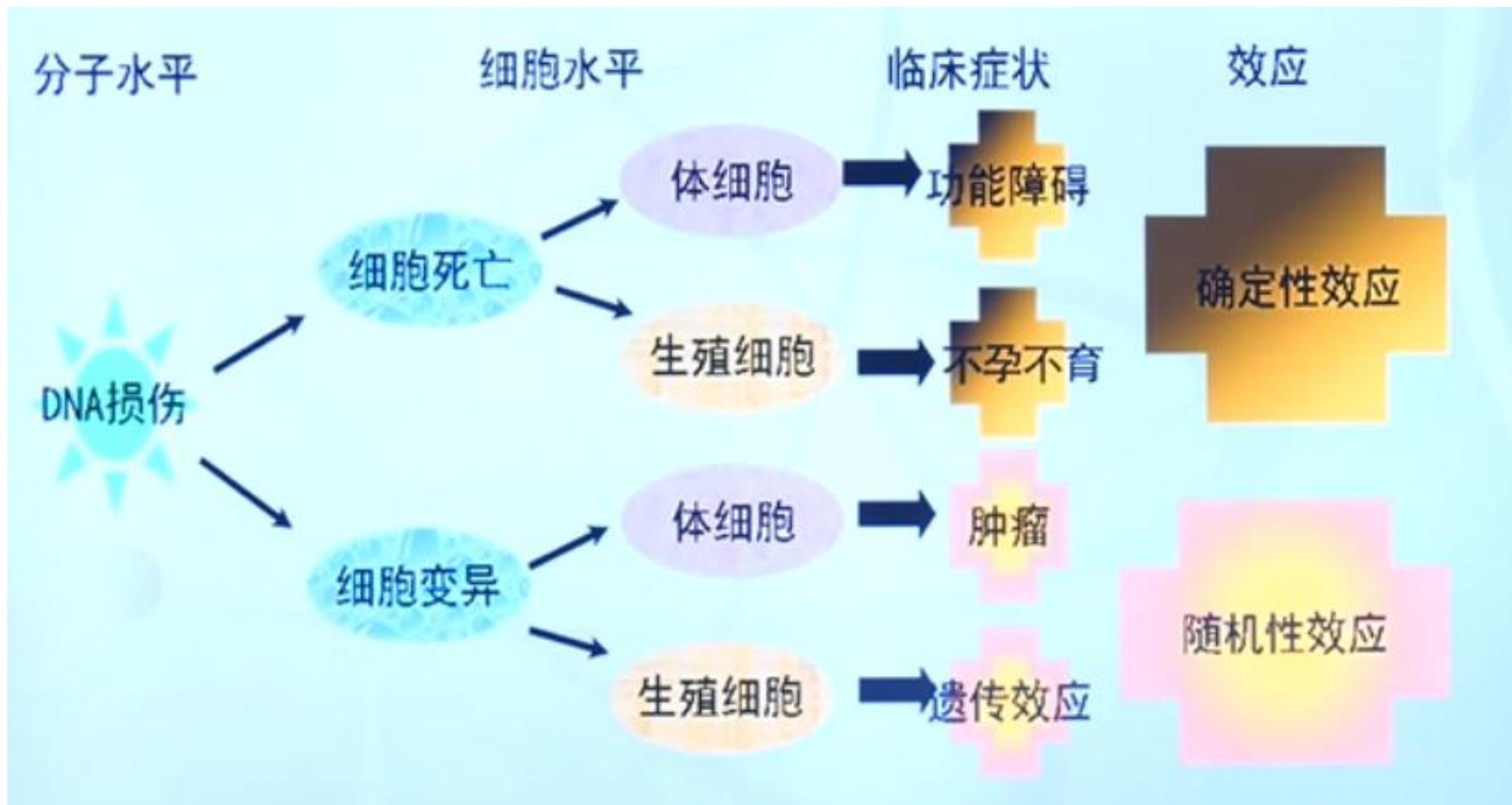
◆ Stochastic Effects:

随机性效应

- Generally assumed to be without a threshold level of dose.
通常无剂量阈值。
- The higher the dose, the greater the probability of occurrence, while severity remains dose-independent.
剂量越高，发生概率越大，而严重程度与剂量无关。
- Example: Cancer induction,
例如：癌症诱发。

Measurement of Exposure 辐射暴露测量

Biological Effects 生物效应



Measurement of Exposure

辐射暴露测量

Factors Affecting Biological Damage

生物损坏影响因素

- ◆ Total Dose 总剂量
- ◆ Dose Rate 剂量率
- ◆ Types of Radiation 辐射类型
- ◆ Area of the Body Irradiated 受照面积
- ◆ Cell Sensitivity 受照部位
- ◆ Individual Sensitivity 个体差异

Measurement of Exposure 辐射暴露测量

External Exposure Assessment 外照射评估

◆ For workplace

对于工作场所

- survey meters should be used to verify that the dose rate in the work area is below dose limits.

使用监测仪器来确认现场剂量率是否低于限值。



附表 1: 检测结果

点位编号	点位描述	表面介质	检测结果($\mu\text{Sv/h}$)
1	屏蔽门门缝(左)	钢	0.07 \pm 0.01
2	屏蔽门门缝(下)	钢	0.07 \pm 0.01
3	屏蔽门门缝(右)	钢	0.07 \pm 0.01
4	屏蔽门门缝(上)	钢	0.08 \pm 0.01
5	屏蔽门中间	钢	0.07 \pm 0.01
6	屏蔽体南侧 1	钢	0.08 \pm 0.01
7	屏蔽体南侧 2	钢	0.08 \pm 0.01
8	屏蔽体南侧 3	钢	0.08 \pm 0.01
9	屏蔽体东侧 1	钢	0.07 \pm 0.01
10	屏蔽体东侧 2	钢	0.07 \pm 0.01
11	屏蔽体东侧 3	钢	0.08 \pm 0.01
12	屏蔽体北侧 1	钢	0.08 \pm 0.01
13	屏蔽体北侧 2	钢	0.08 \pm 0.01
14	屏蔽体北侧 3	钢	0.08 \pm 0.01
15	屏蔽体西侧 1	钢	0.08 \pm 0.01
16	屏蔽体西侧 1	钢	0.08 \pm 0.01
17	屏蔽体西侧 1	钢	0.08 \pm 0.01
18	操作位	钢	0.08 \pm 0.01
19	操作位(本底值)	钢	0.08 \pm 0.01

注: 1、以上数据已校准, 校准系数为 0.97;
2、检测时, 工业 CT 出入口固定朝西照射, 检测屏蔽体西面时无工件, 检测其他面时放置有工件;
3、仪器探头垂直于检测面, 距离屏蔽体约 30cm; 检测 18#, 19# 时仪器探头朝向工业 CT; 每个检测面先通过远测, 以找到最大的点位, 再定点检测, 待仪器读数稳定后每个点间隔 10s 读取 10 个读数;
4、检测结果没有扣除本底值和宇宙射线的响应值。

结论: 香港科技大学(广州)在用的 1 台 YXLON FF35 型工业 CT 在常用最大工作条件下周围剂量当量率均不大于 2.5 $\mu\text{Sv/h}$, 满足《工业探伤放射防护标准》(GBZ117-2022) 的剂量率控制限值。

Measurement of Exposure 辐射暴露测量

External Exposure Assessment 外照射评估

◆ For radiation worker

对于辐射工作人员

- All radiation workers are required to wear a personnel dosimeter to monitor the whole body exposure.

所有辐射工作人员都必须佩戴个人剂量计，以监测全身受照剂量。

- Ring dosimeter should be used if suspected hand exposure is much higher than the whole-body exposure.

如果怀疑手部受到的辐射暴露量远高于全身的辐射暴露量，那么就应该使用环形剂量计。



Personal dosimeter

广东省职业病防治院检测报告
报告编号: FSGR2400488 第 2 页 共 2 页

检测结果: 单位: mSv

序号	姓名	样品编号	剂量当量 $H_p(10)$
1		ZL24012640134200022024.4.01-6.30	<MDL
2		ZL24012640134200032024.4.01-6.30	<MDL
材料表征与制备中央实验室 2024.04.01-06.30			
3		ZL24012640134200042024.4.01-6.30	<MDL
生命科学和生物医学工程学城 2024.04.01-06.30			

(本页以下空白) 检测专用章

Measurement of Exposure 辐射暴露测量

Proper Use of Personnel Dosimeters 正确佩戴个人剂量仪

- ◆ Dosimeters should not be shared with others.
不能将个人剂量仪借给其他人使用。
- ◆ Wear a dosimeter at all times in controlled areas (the name side should face outward).
在辐射工作场所全程佩戴个人剂量仪 (名字面朝外)。
- ◆ Dosimeters must be worn on the chest between the waist and the neck.
个人剂量仪应佩戴在胸部和颈部之间的位置。
- ◆ All dosimeters should be stored in radiation-free area when not in use.
所有剂量计在不使用时应存放在无辐射区域。
- ◆ Finger rings should be worn on the finger of hand most likely to receive the greatest exposure.
如果使用指环式的个人剂量仪，应该戴在最容易受到辐射的那只手上。

◆ There are several methods for internal exposure assessment:

有几种暴露评估方法：

- Indirect: bioassay such as urinalysis,
间接评估：如尿液分析等生物检测方法；
- Direct: whole body counting and thyroid counting.

直接评估：全身计数和甲状腺计数。

◆ Consult LHSD for the appropriate assessment.

请咨询实验室健康与安全处以获取适当的评估方案。



Contents

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◆ Basic Definition of Radiation	辐射基本定义	Radiation Introduction 辐射介绍
◆ Type of Ionizing Radiation	电离辐射类型	
◆ Exposure Hazard and Control	照射风险和控制	
◆ Measurement of Exposure	辐射暴露测量	
◆ Radiation Source	辐射源	Radiation Management 辐射管理
◆ Compliance	合规管理	
◆ Emergency Response	应急响应	

Radiation Source 辐射源

Sealed Source 放射源（密封）

- ◆ Sealed Source refers to radioactive material that is **permanently sealed in a container or has a tight cladding and is in solid form**, excluding materials within the scope of the nuclear fuel cycle of research reactors and power reactors.

放射源，是指除研究堆和动力堆核燃料循环范畴的材料以外，**永久密封在容器中或者有严密包层并呈固态的放射性材料。**

- ◆ The radionuclides contained within it **emit α , β , or γ** during decay.

其内部的放射性核素在衰变过程中会**发射 α ， β 或 γ** 。



Radiation Source 辐射源

Sealed Source 放射源（密封）

◆ Based on IAEA standards, classified by potential hazard to health and environment

参照国际原子能机构标准，按对健康和环境的潜在危害程度分类

- Category I (I类) **Fatal within minutes to 1 hour** of unprotected exposure 无防护下接触**几分钟至1小时可致人死亡**
- Category II (II类) **Fatal within hours to days** of unprotected exposure 无防护下接触**几小时至几天可致人死亡**
- Category III (III类) **Permanent injury within hours**; fatal within days to weeks **几小时可致永久损伤**; 数天至数周可致命
- Category IV (IV类) Generally no permanent injury; may cause reversible damage 基本无永久损伤; 可能造成可恢复损伤
- Category V (V类) No permanent injury (activity \geq exemption level) 不会造成永久损伤 (活度 \geq 豁免水平)

Radiation Source 辐射源

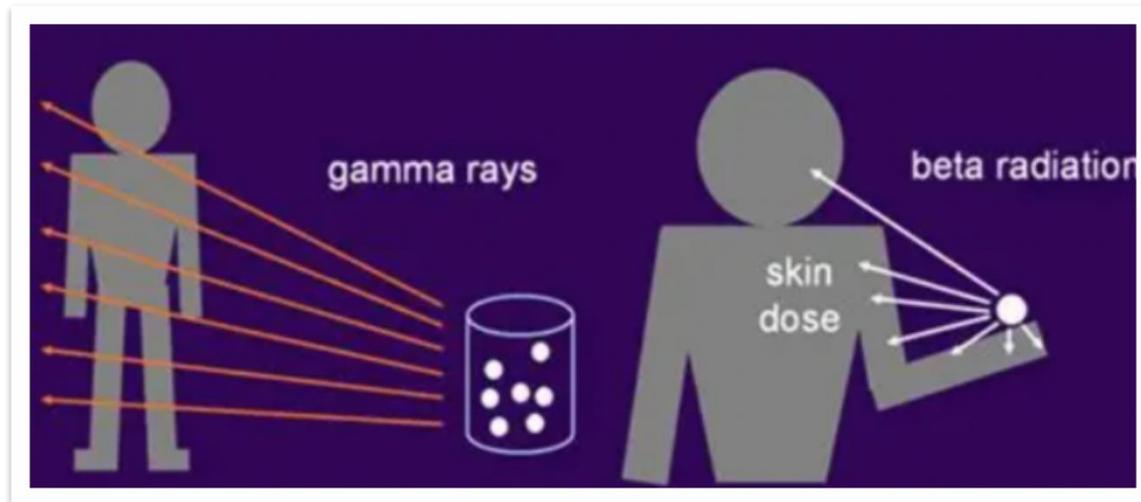
General Hazard of Sealed Source 放射源（密封）的风险

- ◆ **Sealed Sources are primarily an external hazard**, but would pose an internal hazard if the cover is damaged.

放射源有一般是外照射风险, 但如果密封壳破损, 则可能存在内照射风险。

- ◆ They present a potential hazard only when an individual is exposed to the source.

只有当人员暴露于源的辐射场中时（受到照射时），才会构成潜在危害。



- ◆ Sealed sources shall be properly placed to **avoid damage**.

妥善放置，**避免破损**。

- ◆ **Leak tests** shall be carried out periodically.

定期对密封源进行**泄漏检测**。

- ◆ Security measures are in place, e.g., access control and video surveillance, **to prevent theft**.

有充足的安全保卫措施（如门禁管控，监控系统等），**避免被盗**。

Radiation Source 辐射源

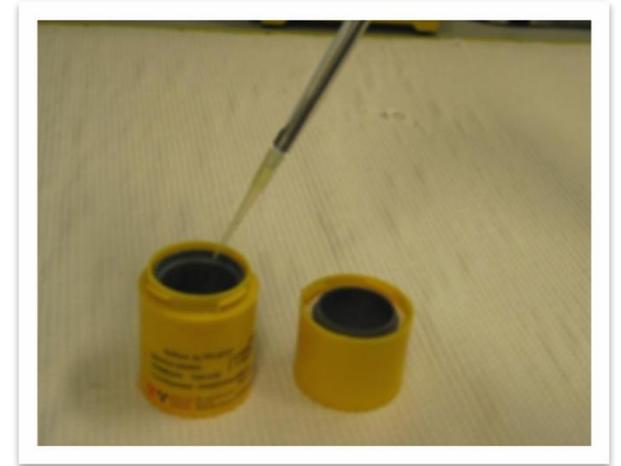
Unsealed Source 非密封放射性物质

- ◆ Unsealed Source refers to radioactive material that is **not permanently sealed in a casing or firmly consolidated in a coating layer.**

非密封放射性物质，是指**非永久密封在包壳里或者紧密地固结在覆盖层里的放射性物质。**

- ◆ The radionuclides contained within it **emit α , β , or γ** during decay.

其内部的放射性核素在衰变过程中会**发射 α ， β 或 γ 。**



Radiation Source 辐射源

Unsealed Source 非密封放射性物质

- ◆ In compliance with national regulations, workplaces using Unsealed Sources are classified into three risk grades (甲, 乙, 丙), from highest to lowest
- 国家对非密封放射性物质的使用场所进行管控, 按照风险等级由高到低分为甲、乙、丙三个级别。

GB 18871—2002

附录 C
(标准的附录)
非密封源工作场所的分级

C1 非密封源工作场所的分级

应按表 C1 将非密封源工作场所按放射性核素日等效最大操作量的大小分级。

表 C1 非密封源工作场所的分级

级 别	日等效最大操作量/Bq
甲	$>4 \times 10^9$
乙	$2 \times 10^7 \sim 4 \times 10^9$
丙	豁免活度值以上 $\sim 2 \times 10^7$

Radiation Source 辐射源

Hazard of Unsealed Source 非密封放射性物质的风险

- ◆ An unsealed source presents both external and internal exposure hazards.

非密封放射性物质同时拥有外照射和内照射风险。

- ◆ Exposure Pathway into the body (internal exposure)放射性物质进入体内的途径 (内照射)

- Oral Ingestion (Digestive Tract)

经口，消化道的摄入

- Inhalation (Respiratory Tract)

经呼吸道的吸入

- Skin/Wound Absorption.

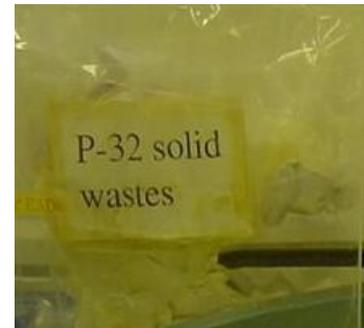
经皮肤/伤口进入



Radiation Source 辐射源

Control Measure of Unsealed Source 非密封放射性物质的管控

- ◆ Good housekeeping 整洁的工作场所环境
- ◆ PPE: e.g., lab coat, disposable gloves, safety glasses 个人防护:如实验服, 手套, 安全眼镜
- ◆ Swipe tests shall be carried out periodically. 定期开展擦拭测试
- ◆ Place absorbent paper on the workbench. 操作台面放置吸附纸
- ◆ Labeling: tools, containers, ... 辐射安全标识: 工具, 容器, ...



Radiation Source 辐射源

Radionuclide 放射性核素

- ◆ **Sealed/Unsealed Sources are materials that contain one or more radionuclides.** A radionuclide is an unstable isotope of an element that decays or disintegrates spontaneously, emitting ionizing radiation. For example.

H-3 emits β during decay, Am-241 emits α and low-energy γ .

密封/非密封放射物质内含有的一种或多种放射性核素。放射性核素是指元素的一种不稳定同位素，它能自发地衰变或分解，并释放出电离辐射。例如，H-3在衰变时释放 β 粒子，而Am-241则主要释放 α 粒子及低能 γ 射线。

- ◆ The number of radioactive atoms in a radioactive material will decrease with the passage of time;

Generally, the risk associated with a radioactive material goes down as time passes.

放射性物质中放射性原子的数量会随着时间的推移而减少；一般来说，**风险随时间流逝而降低。**

- ◆ Activity is the number of atomic nuclei of a radionuclide that decay per unit time.

放射性活度是指放射性核素在单位时间内发生衰变的原子核数。

SI unit: becquerel (Bq)

国际单位：贝可 (Bq)

$$1 \text{ Bq} = 1 \text{ disintegration / sec}$$

Conventional unit: curie (Ci)

传统单位：居里 (Ci)

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$$

Radiation Source 辐射源

Radioactive (Physical) Half-life 放射性活度（物理）半衰期

- ◆ The physical half-life ($T^{1/2}$) is the time required for the number of radioactive atoms of a particular radionuclide to decrease to one-half of its initial value through spontaneous decay.

物理半衰期 ($T^{1/2}$) 是指特定放射性核素的原子核数目，通过自发衰变减少到其初始值的一半而所需的时间

- ◆ Radioactivity as a function of time:

放射性活度与时间的函数关系：

$$A = A_0 e^{-\lambda t} \quad \lambda = \ln(2) / T^{1/2} \text{ (half-life 半衰期)}$$

- Where A is activity, A_0 is the original activity, λ is decay constant, t is time taken

其中， A 表示（当前）活度， A_0 表示初始活度， λ 表示衰变常数， t 表示所经历的时间

Radiation Source 辐射源

Radioactive (Physical) Half-life
放射性活度 (物理) 半衰期

- ◆ The initial Physical Half-life of commonly used beta:

常用 β 的初始物理半衰期:

Radionuclide	Half-life	Emax (MeV)
H-3	12.3y	0.018
C-14	5730y	0.154
P-32	14.3d	1.71
S-35	88d	0.167
Ca-45	165d	0.254

Radiation Source 辐射源

Irradiating Apparatus (IA) 射线装置

- ◆ IA refers to X-ray machines, accelerators, neutron generators, and devices containing radioactive sources.

射线装置，是指X线机、加速器、中子发生器以及含放射源的装置。

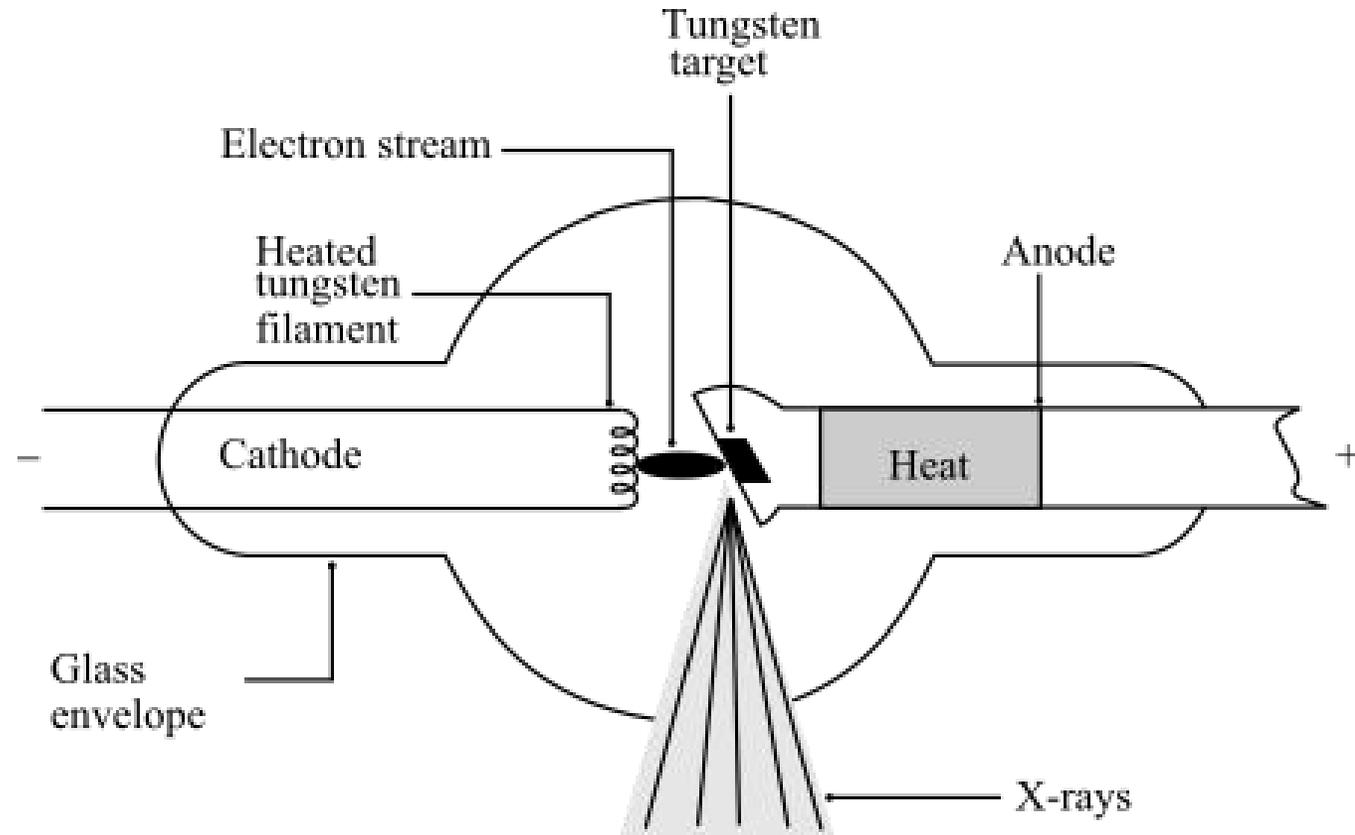


Radiation Source 辐射源

Irradiating Apparatus (IA) 射线装置

- ◆ When an IA is powered on, high-voltage accelerated electrons bombard the metal target (e.g., Tungsten), generating X-rays through bremsstrahlung and electron transitions.

设备通电后，高压加速的电子轰击金属靶（如钨），通过轫致辐射和电子跃迁产生X射线。



- ◆ Based on the **potential hazard level** to human health and the environment, IA are **classified, in descending order of risk, into Category I, Category II, and Category III.**

根据射线装置对人体健康和环境的**潜在危害程度，从高到低将射线装置分为 I 类、II 类、III 类。**

- Class I: Accidental short-term exposure may cause severe radiation injury to individuals.

I 类：事故时短时间照射可以使受到照射的人员产生严重放射损伤；

- Class II: Accidental exposure may cause relatively severe radiation injury.

II 类：事故时可以使受到照射的人员产生较严重放射损伤；

- Class III: Accidental exposure generally would not cause radiation injury

III 类：事故时一般不会使受到照射的人员产生放射损伤。

◆ Shielding/Barriers

屏蔽/屏障:

- X-ray units shall be designed with shielding so that regulatory dose limits are not exceeded ($2.5 \mu\text{Sv/h}$).

X 射线设备的设计应包含屏蔽装置，以确保不超过规定的剂量限值($2.5 \mu\text{Sv/h}$)。

- All ports of an analytical X-ray unit shall be covered with a radiation shield when not in use.

分析用X射线装置的所有端口在非使用期间，必须用辐射屏蔽罩覆盖。

Shielding

屏蔽体



Radiation Source 辐射源

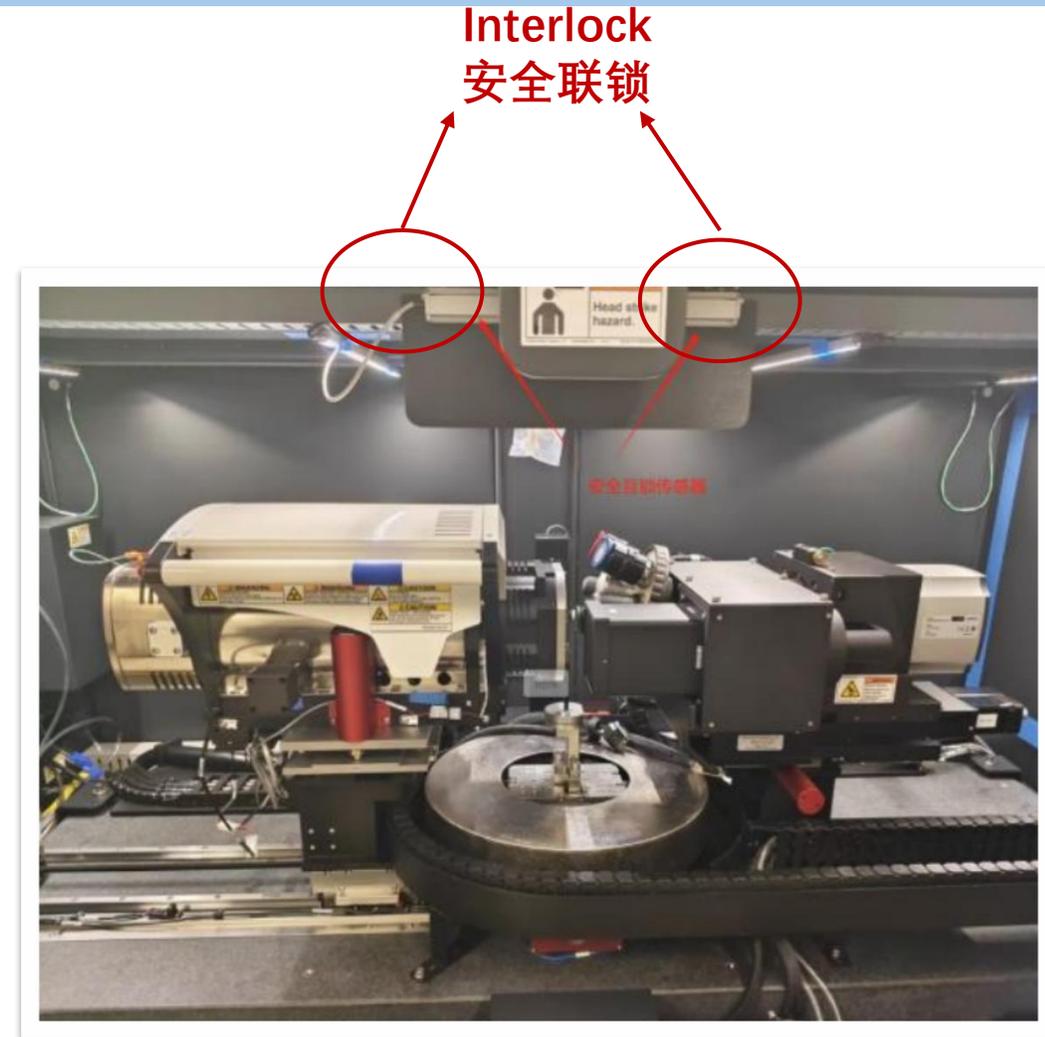
Safety Guard of Irradiating Apparatus (IA) 射线装置的安全防护

◆ Interlocks

安全联锁:

- Interlock is a critical safeguard. The system will automatically power down when the shielding door is not properly closed, preventing workers from exposure to X-ray .

安全联锁是射线装置的关键保障。屏蔽门未关闭时，系统将自动断电，避免人员意外暴露在X的照射下。



◆ Interlocks

安全联锁:

- This system should be designed so that the high voltage system is grounded automatically if an interlock is opened.

该系统的设计应确保：一旦联锁被触发（如防护门被打开），高压系统能自动接地放电。

- For open beam systems, the entry-door may interlock with the x-ray system.

对于开放式光路系统，其入口门应与X射线系统实现联锁。

◆ Warning Signs

警示标识:

- A 'CAUTION' sign shall be posted at the room entrances where x-ray units are operated and at the x-ray unit enclosure.

必须在运行X射线设备的房间入口处及设备防护罩上张贴“注意”警告标志。

- An approved operating procedure shall be posted on or next to all x-ray.

必须在所有X射线设备上或其旁边张贴经批准的操作规程。

- When X-ray is 'ON', the entrance light must be 'ON' simultaneously to alert other personnel.

当X射线处于“开启”状态时，入口的警示灯必须同步点亮，以警告其他人员。

◆ Key control

钥匙控制

- X-ray units with key-controlled console should have the key removed and secured when the unit is left unattended.

对于带有钥匙控制台的X射线设备，当设备处于无人看管状态时，必须将钥匙取下并妥善保管。



◆ X-ray System Survey

X射线系统巡测

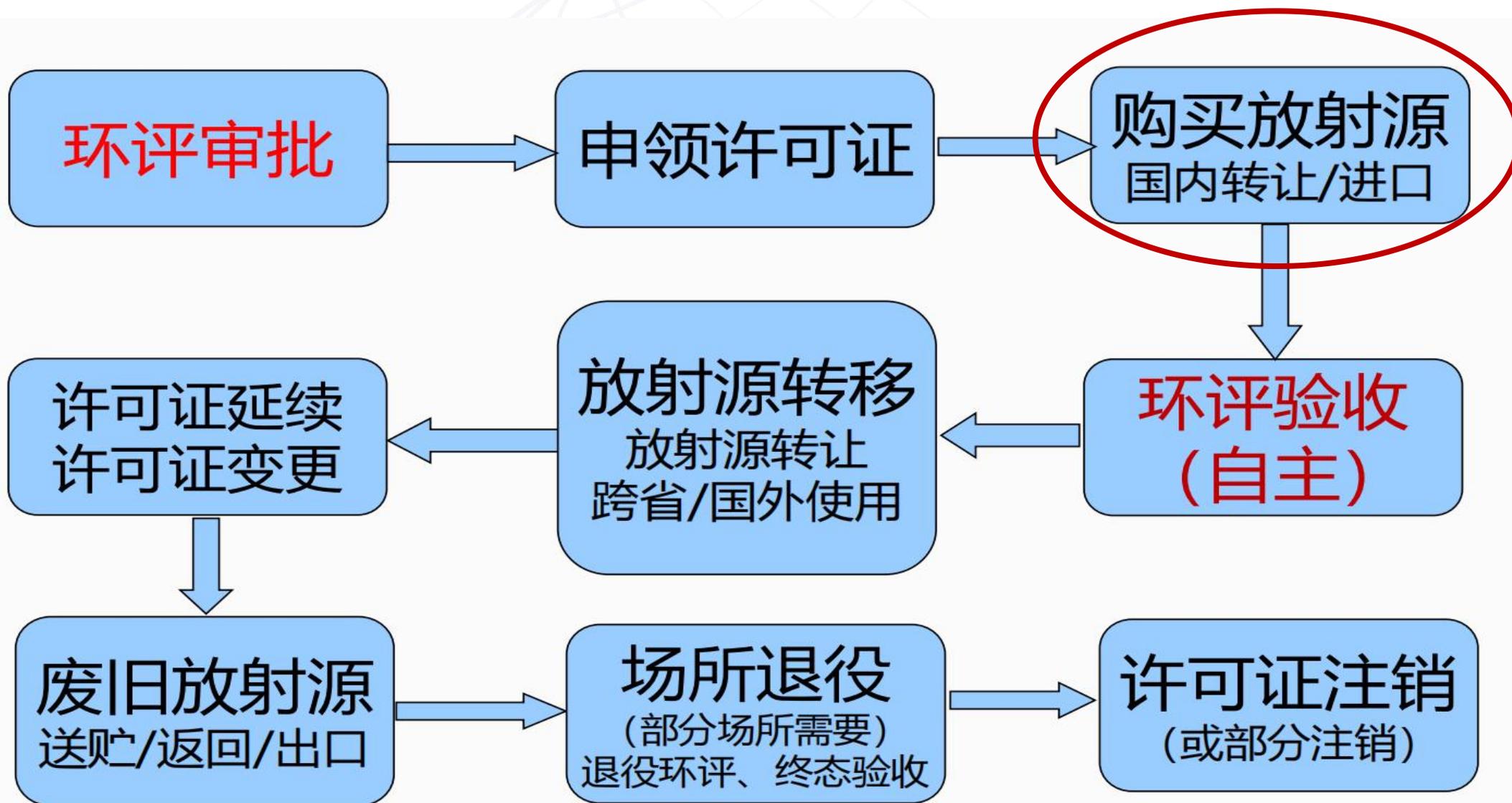
- The appropriate X-ray survey instruments should be available to **survey the X-ray for leakage periodically.**
必须配备适用的X射线巡测仪器，并**定期对设备进行辐射泄漏检测。**
- **Interlocks shall be checked at least once every 6 months** to ensure proper function.
安全联锁装置应至少每6个月检查一次， 以确保其功能正常。
- Interlocks that malfunctioned shall be repaired and re-tested before the unit can be operated again.
发生故障的联锁装置必须在经过维修并重新测试合格后，设备方可重新投入运行。



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◆ Pre-Approval 事前审批

- For the import (export) of Unsealed Source, apply to the competent department of ecological environment of the State Council for approval once every six months.

进口（出口）非密封放射性物质的，每6个月报国务院生态环境主管部门审批一次。

- For the import (export) of Sealed Source, apply for approval to the competent department of ecological environment of the State Council before import.

进口（出口）放射源的，应当在进口前报国务院生态环境主管部门审批。

◆ Post-approval Filing 事后备案

- Within 20 days from the completion of the activity, Import and using units shall respectively submit the relevant documents to the provincial regulators where they are located for filing.

活动完成之日起20日内，进口单位和使用单位分别将相关材料报送各自所在地的省级生态环境主管部门。

◆ Pre-Approval 事前审批

- The transfer of Sealed and Unsealed Source requires the receiving unit to obtain prior approval from the local regulatory authority. However, for batch transfers of Unsealed Source, approval may be applied for on a consolidated basis.

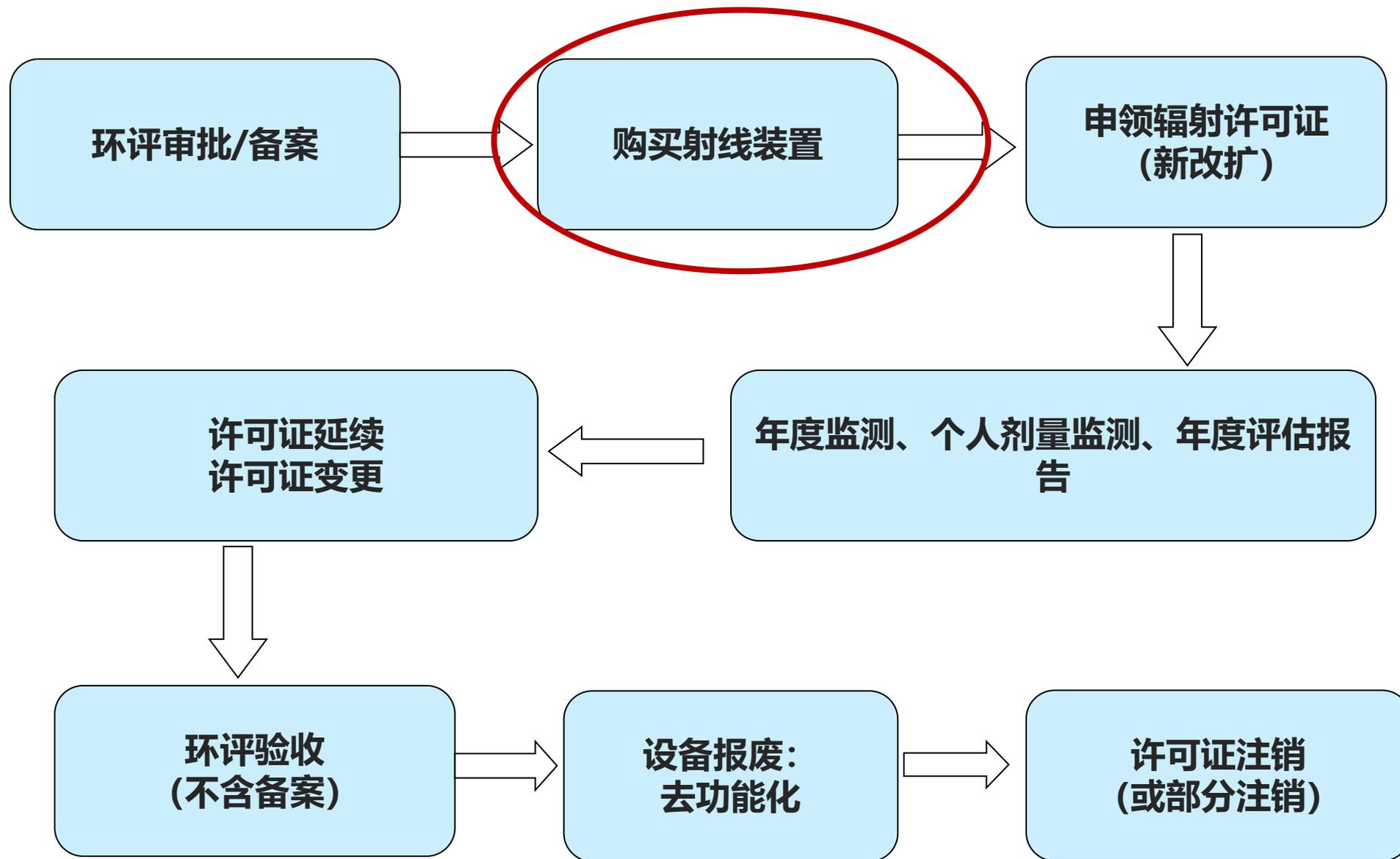
放射性同位素的转让，均须由转入单位事先向所在地审管部门报批；唯分批次转让非密封放射性物质的，可每6个月集中报批一次。

- Transfer is only permitted between licensed units. It is strictly prohibited for unlicensed or out-of-scope units.
- 放射性同位素仅限于在持证单位之间转让，严禁向无证或超范围单位转让。

◆ Post-approval Filing 事后备案

- Both receiving and transferring units must file the approval form with their respective provincial authority within 20 days of transfer completion.

转入、转出双方应于转让完成之日起20日内，将放射性同位素转让审批表分别报送各自所在地省级生态环境主管部门。



- ◆ For Sealed Source, Unsealed Source , IA, or source-containing equipment that comply with the exemption criteria of the 《电离辐射防护与辐射源安全基本标准》（GB 18871-2002）, if the manufacturer, importer, or HKUST (Guangzhou) has completed the exemption filing with the ecological and environmental authorities, their on-campus use activities are exempt from safety supervision by the regulatory authorities.

对于符合国家标准（GB 18871-2002）豁免条件或有条件豁免的含源设备，若其生产或进口单位（或香港科技大学（广州））已完成生态环境部门豁免备案，其在校内的使用活动可免于审管部门的安全监管。

- ◆ Such exempted IA or isotopes are not required to conduct环境影响评价 or obtain a 《辐射安全许可证》， nor are they required to participate in external radiation safety examinations. However, personnel must complete and pass the radiation safety training course organized by the LHSD of HKUST (Guangzhou).
此类豁免射线装置或同位素无需进行环境影响评价和办理《辐射安全许可证》，也无需参加外部辐射安全考核，但人员须完成香港科技大学（广州）实验室健康与安全处组织的辐射安全培训并考核合格。
- ◆ To protect the health and safety of workers, LHSD also recommends that operators wear personal dosimeters and complete occupational health examinations.
为保护从业人员的健康和安全，实验室健康与安全处也建议上述豁免的放射性同位素或射线装置的从业人员佩戴个人剂量仪和参加职业健康体检。

◆ The following types of projects are exempt from the requirement to prepare an 环境影响评价文件 and may directly apply for a 《辐射安全许可证》：

如下项目无需要编制环境影响评价文件，可直接申请《辐射安全许可证》：

- Adding Sealed Sources or IA of the **same or lower category** to existing licensed premises, **without changing the type of activity**. (Includes adding new radionuclides or IA models.)

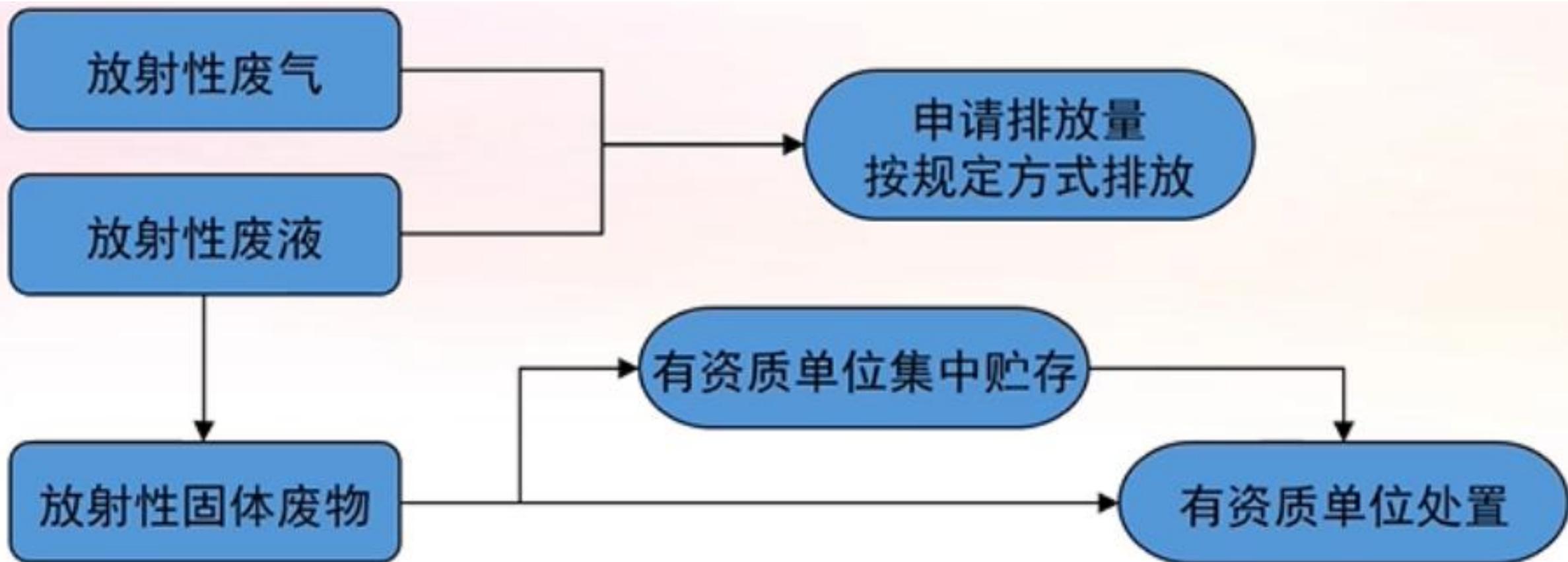
在已许可使用高类别放射源/射线装置的场所，**不改变活动种类，增加使用同等类别或低类别的放射源或射线装置**。（包括增加核素种类、增加同种型号或不同型号、参数的射线装置）

- At existing licensed premises for Unsealed Source, adding new radionuclides or increasing handling quantities, **provided the classification level of the premises is not raised**.

在已许可的非密封放射性物质工作场所，增加操作的核素种类或操作量，**且增加后不提高场所的级别监督管理**。

- ◆ The above-mentioned projects **should not involve** major construction work. They must be carried out within the original radiation work premises, utilizing the existing radiation safety shielding, protection, and interlock facilities (or with only minor modifications to the existing facilities sufficient to meet radiation safety and protection requirements).

上述项目**不应涉及**主体施工建设，而是在原辐射工作场所内，利用原有的辐射安全屏蔽、防护和连锁设施直接开展项目（或对原有设施进行简单的改造即能满足辐射安全与防护要求）。



- ◆ 熟悉并遵守相关《辐射安全工作计划》中的内容
- ◆ 设置醒目辐射安全标志。设立受控区域，严格授权准入。

Be familiar with and abide by relevant

"Radiation Safety Work Plan"

Post clear radiation signs. Establish controlled access zones.

目录

- 一、房间信息
- 二、风险评估
- 三、放射性核素限值
- 四、安全操作规程清单
- 五、辐射工作人员清单&培训记录
- 六、放射性废物处置
- 七、非密封放射性物质泄漏现场处置方案
- 八、射线意外释放现场处置方案（射线装置）
- 九、放射源突发事件现场处置方案
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◆ Assessment & Initial Action 评估与初步行动

- If a Sealed Source is dropped or impacted but appears intact, maintain distance, retrieve with long-handled tools, and contact LHSD for testing.

若放射源跌落、撞击**但外壳完好**，保持距离，使用长柄工具谨慎回收，并联系LHSD进行检测。

- If the seal is damaged or dosimeters alarm, instruct all personnel to evacuate immediately. Then report it.

若**密封壳破损或剂量仪报警**，立即通知所有人员撤离，并报告。

◆ Access Control and Assistance 现场警戒和协助

- Guard the entrance from a safe distance to prevent entry. Assist the response from a safe area.

与实验室保持一定安全距离，同时保持实验室入口或通道在视线范围内，防止无关人员进入实验室；在安全区域等待并协助应急小组。

Emergency Response 应急响应

Sealed Source (Loss or Theft) 放射源 (丢失或被盜)

◆ Report 报告

- Report immediately (020-8833 0110)

立刻报告。

◆ Assist in Tracking & Search 协助追踪与搜寻

- Support the Emergency Team in locating the source by reviewing surveillance footage and issuing search notices.

配合应急小组通过调阅监控、发布寻源通知等方式全力查找放射源下落。

Emergency Response 应急响应

Unsealed Source (Spill) 非密封放射性物质（泄漏）

◆ Spill Control (Liquid) 泄漏控制（液态）

- Evacuate Immediately. **Close ventilation and doors to allow aerosols to settle for at least 30 minutes**, then Report (020-8833 0110) .

所有人员立即**撤离实验室。关闭通风和门窗，让气溶胶沉降至少30分钟**,然后报告（020-8833 0110）。

- Place warning sign at the door to prevent entry, wait for the emergency response team to arrive.

在门口放置警告标志防止他人进入,等待应急小组的到来。

- If safe, confine the spill using appropriate materials

若情况安全，请使用合适的材料控制泄漏。

- After cleanup, site re-entry must be confirmed by LHSD.

清理完后，现场恢复前需得到LHSD的确认。



Emergency Response 应急响应

Unsealed Source (Spill) 非密封放射性物质（泄漏）

◆ Area Decontamination 区域除污

- Wear gloves and protective clothing.
穿戴手套和实验服。
- Use soap, water or other appropriate materials to clean up, start at periphery and work toward the center.
使用肥皂，水或其他适当的材料清洁，从外向内进行除污。
- Do not use scrub brushes. Survey continuously.
避免使用刷子。持续监测。



◆ Personnel Decontamination 人员除污

- Internal contamination: report to LHSD.
体内污染：报告给实验室健康与安全处。

- External contamination:

体外污染:

- Remove and seal all potentially contaminated clothing in a plastic bag.
脱去所有外层衣物。将其放入塑料袋并密封好。
- Gently wash with detergent.
用温和洗涤剂和水轻柔清洗皮肤。
- Check for contamination using a survey meter or wipe test.
使用监测仪或擦拭实验监控去污效果。
- Avoid scrubbing vigorously to prevent aerosol generation.
切勿用力刷洗皮肤，以免产生气溶胶或损伤皮肤。

◆ Accident Risk Description 事故风险描述

- Interlock failure or damaged shielding may cause accidental radiation release. A dosimeter alarm indicates a leak.

安全联锁发生故障，屏蔽体破损，正常工作状态下个人剂量报警仪发出报警声都有可能存在射线意外释放。

◆ Emergency Procedures 应急程序

- Immediate Evacuation 通知所有人员立即撤离实验室。
- Emergency Power Shutdown 紧急断电。
- Reporting 报告
- On-Site Security 现场警戒
- Device Inspection by manufacturer before restarting. 由厂家对装置进行全面检修，合格后方可启用。

Reference

参考

- ◆ 《中华人民共和国放射性污染防治法》（2003年颁布）
- ◆ 《中华人民共和国职业病危害防治法》（2018年修订）
- ◆ 《放射性同位素与射线装置安全和防护条例》（2019年修订）
- ◆ 《放射性同位素与射线装置安全许可管理办法》（2021年修订）
- ◆ 《放射性同位素与射线装置安全和防护管理办法》（2011年颁布）
- ◆ 《电离辐射防护与辐射源安全基本标准》（GB 18871-2002）
- ◆ 关于发布放射源分类办法的公告（国家环境保护总局公告 2005年 第62号）
- ◆ 关于发布《射线装置分类》的公告（环境保护部 国家卫生和计划生育委员会 2017年 第66号）
- ◆ 关于《建设项目环境影响评价分类管理名录》中免于编制环境影响评价文件的核技术利用项目有关说明的函（环办函〔2015〕1758号）
- ◆ 国家和安全局-[核能]我们日常生活中会受到哪些辐射?/[辐射防护]我们时时刻刻在接触放射性——天然放射性