Exhibition on Environmental Radiation in the Exhibition Hall of the Hong Kong Observatory

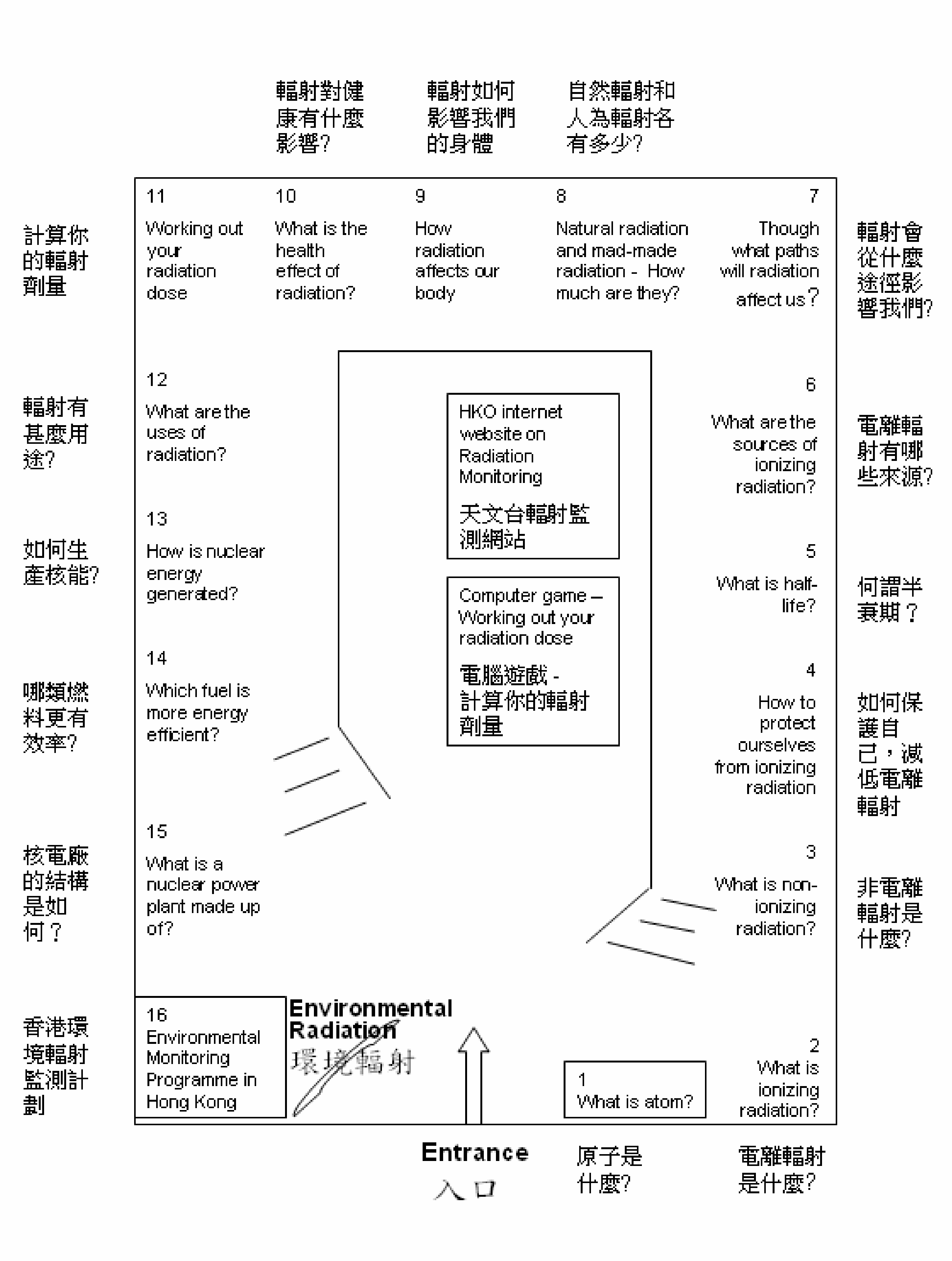
天文台展覽館

環境輻射展覽廳展品簡介

Hong Kong Observatory

香港天文台

Location of Displays
展品位置示意圖



For reference of teachers only

Nov 2008

Contents

Display No. 1

What is atom?

Text of the exhibit

All materials are made up of tiny particles called atoms. At the centre of an atom is the nucleus. The nucleus consists of uncharged neutrons and positively charged protons. It makes up virtually all the mass of the atom. Revolving round the nucleus are negatively charged electrons.

所有物質都是由細小的原子組成。原子的中心是原子核，由不帶電荷的中子及帶正電荷的質子組成，原子核集中了差不多整顆原子的質量。環繞原子核運行是帶負電荷的電子。

Note to the teacher

The exhibit highlights the fact that despite the immense diversity of sizes of different objects in the universe, all matters, including our human bodies, are made up of sub-atomic particles called elementary articles. A hierarchy of objects according to their sizes are shown in the exhibit.

這個展品表明出一個事實：儘管在宇宙中有很多不同大小的物體，所有的物質，包括我們的身體，都是由細小的原子粒子所組成。展品陳列了物體大小的等級。

Structure of an atom

All matters are made up of tiny units called atoms. Every atom has a nucleus which is surrounded by a cloud of electrons. The nucleus consists of uncharged neutrons and positively charged protons. Negatively charged electrons travel around the nucleus in their orbits, similar to the way planets moving around the sun.

The numbers of protons and electrons in an atom are normally the same, giving an uncharged atom. The nucleus of the smallest atom - the hydrogen atom, contains only one proton. Whereas those of the bigger ones contain large numbers of protons and neutrons. For example, the carbon-12 nucleus contains 6 protons and 6 neutrons. The uranium-238 nucleus contains 92 protons and 146 neutrons.

Nuclei of most atoms are stable (i.e. tend to remain as they are); but some nuclei, in particular, those large ones, are unstable. These unstable nuclei may release particles or electromagnetic waves spontaneously to return to their stable states. This process is called decay. The unstable nuclei are said to be radioactive and called radionuclides. The released particles and electromagnetic waves are called radiation.

原子的結構

世上所有物質都是由細小的原子組成，而每粒原子有一個被電子包圍著的原子核。細小的原子核內含不帶電荷的中子及帶正電荷的質子，而帶負電荷的電子則沿軌道環繞原子核運行，情況就好像行星環繞太陽運行一樣。

通常，原子內的質子和電子的數目是相同的，所以原子不帶電荷。氫是最細小的原子，它的原子核內只有一顆質子。而較大的原子，其原子核內質子及中子的數目則更多。例如，碳-12 的原子核內有 6 顆質子及 6 顆中子，而鈾-238 的原子核內便有 92 顆質子及 146 顆中子。

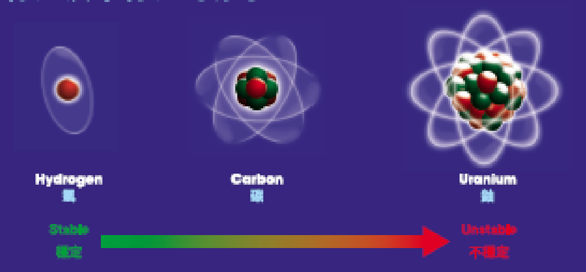
大部分原子的原子核都是穩定的，即是說會長期保持原來的狀態。不過，有些原子核，尤其是那些較大的原子核，卻是不穩定的。這些不穩定的原子核具有放射性，它會自發地釋放出粒子或電磁波，從而回復到穩定的狀態，這個過程稱爲衰變。這些具有放射性的原子核稱爲放射性核素，而放出的粒子和電磁波則統稱輻射。

Display No. 2

What is ionizing radiation?

WHAT IS IONIZING RADIATION?
電離輻射是什麼？

STABLE AND UNSTABLE ATOM
穩定及不穩定的原子



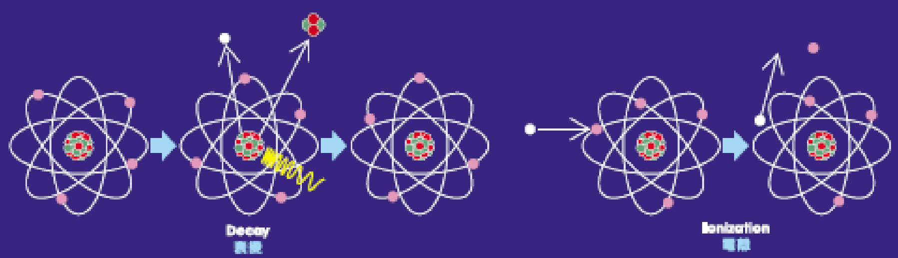
The nucleus of the smallest atom - the hydrogen atom, contains one proton only. But those of the larger atoms contain many protons and neutrons. A uranium - 238 nucleus contains 92 protons and 146 neutrons.

The nucleus of most atoms is stable, but some nuclei, in particular those larger ones, are unstable.

氫原子是最小的原子，它的原子核祇有一顆質子，較大的原子則含有許多質子和中子，鈾－238 原子核便有 92 顆質子及 146 顆中子。

大部分原子的原子核都是穩定的，不過有些原子核，尤其是一些較大的原子核，卻是不穩定的。

DECAY AND IONIZING RADIATION
衰變及電離輻射



An unstable nucleus emits particles and energy. This process is called decay.

These particles or energy are collectively called radiation.

Radiation can be ionizing or non-ionizing. If the energy of radiation is high enough to remove electrons from atoms, thus creating positively charged ions, it is called ionizing radiation.

不穩定原子核放射出粒子及能量，過程稱為衰變。

這些粒子或能量統稱輻射。

輻射可分為電離及非電離輻射。「電離輻射」名稱的由來，是因為輻射能量高，足以將其他原子的電子撞擊出外，產生帶正電的電離子。

Text of the exhibit

Stable and unstable atom

The nucleus of the smallest atom - the hydrogen atom, contains one proton only. But those of the larger atoms contain many protons and neutrons. A uranium-238 nucleus contains 92 protons and 146 neutrons.

The nucleus of most atoms is stable, but some nuclei, in particular those larger ones, are unstable.

穩定及不穩定的原子

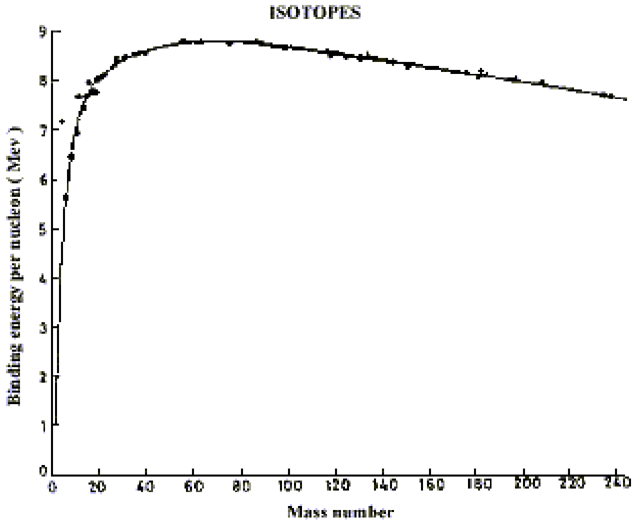
氫原子是最小的原子，它的原子核祇有一顆質子。較大的原子則含有許多質子和中子，鈾-238 原子核便有 92 顆質子及 146 顆中子。

大部分原子的原子核都是穩定的，不過有些原子核，尤其是一些較大的原子核，卻是不穩定的。

Note to the teacher

Unstable nuclei

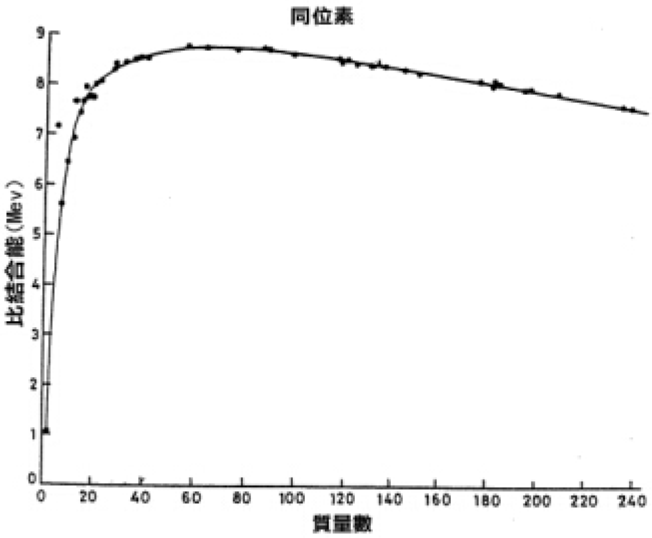
The stability of a nucleus can be described in terms of a number of parameters. One such parameter is the binding energy of particles inside the nucleus, i.e. the nucleons. The total binding energy of a nucleus is defined as the energy that would be required to separate the nucleus into separate nucleons. In other words, the same amount of energy will be given off when stand-alone nucleons come together to form the nucleus. When the binding energy per nucleon is plotted against the mass number, i.e. total number of protons and neutrons in a nucleus (the bottom figure), it is found that the curve peaks around the mass number 56, i.e. the iron nucleus. This indicated that total energy of the iron nucleus is the lowest. In term of energy, nuclei larger than that of iron will have a tendency to break up while smaller nuclei would have a tendency to combine to form larger nuclei.



Binding energy per nucleon as a function of mass number
(total number of protons and neutrons)

不穩定的原子核

原子核的穩定度可以用若干參數來描述，其中一個參數是核粒子的結合能。原子核的總結合能是指把原子核分開成爲獨立核粒子所需的能量。換句話說，獨立核粒子結合組成一個原子核，就會釋放出相等於該原子核的總結合能的能量。如果把原子核內每顆核粒子的平均結合能(又稱比結合能)與質量數 (原子核中的質子和中子的總數) 繪製成圖(下圖)，便可發現圖中曲線在質量數大約等於 56 (即鐵原子核) 時到達最高點，即是鐵原子核的總體能量最低。因此，如以能量作爲考慮因素，任何大於鐵的原子核，會傾向分裂，放出多餘的能量。而較小的原子核則傾向互相結合，組成較大的原子核。



原子核的結合與質量數 (質子和中子總數) 的關係圖

Text of the exhibit

Decay and Ionizing Radiation

An unstable nucleus emits particles and energy. This process is called decay.

These particles or energy are collectively called radiation.

Radiation can be ionizing or non-ionizing. If the energy of radiation is high enough to remove electrons from atoms, thus creating positively charged ions, it is called ionizing radiation.

衰變及電離輻射

不穩定原子核放射出粒子及能量，過程稱爲衰變。

這些粒子或能量統稱輻射。

輻射可分爲電離及非電離輻射。電離輻射的能量高，足以將其他原子的電子撞擊出外，產生帶正電的電離子。

Note to the teacher

Ionizing radiation

Ionizing radiation includes high speed particles and high energy electromagnetic waves. Their energy is high enough to remove orbital electrons from atoms, thus giving rise to positively charged ions and negatively charged electrons.

Apart from x-rays which are emitted by excitation of electron clouds, most of the ionizing radiation come from the decay of unstable nuclei. Brief descriptions of different types of ionizing radiation are given below:

(1) Alpha (α) particles

α particles, identical to helium nuclei, are positively charged particles consisting of two protons and two neutrons. As they are positively charged, their motion will be affected by an electromagnetic field. In general, heavy atoms (having atomic numbers greater than 82) would tend to emit α particles. Uranium and radium are examples of α emitting nuclei. As α particles are relatively large and positively charged, they ionize matter easily and lose their energy very quickly. The penetrating power of α particles is the lowest among all types of ionizing radiation. α particles can be stopped easily by the outer layer of skin or a sheet of paper.

However, if α particles are taken into our body by inhalation or ingestion, such as inhaling part of a radioactive plume, a particles can directly affect tissues in the body. Although their penetrating power is weak, their ionization power is strong. The severity of biological effects inflicted will not be lower than other radiations.

(2) Beta (β) particles

β particles are high speed electrons. Being negatively charged, they are affected by an electromagnetic field. As they are much smaller than α particles, β particles have greater penetrating power. A sheet of aluminium a few millimetres thick can stop them. Many radioactive materials will emit β particles when they decay.

(3) Gamma (γ) rays and x-rays

γ rays and x-rays are high energy electromagnetic waves. They have no mass and no electrical charge. They travel in straight lines in an electromagnetic field. Energy is transmitted in the form of electromagnetic waves similar to visible light, except that they have higher frequency and energy. γ rays and x-rays have great penetrating power and can pass through human body. Thick barriers of lead or concrete can stop them.

γ rays and x-rays are similar, the major difference is their origins. γ rays are emitted from the nuclei of unstable atoms during radioactive decay, while x-rays are from the electron cloud as the result of electron excitation.

(4) Neutrons

Neutrons have no charge and are constituents of the atomic nucleus. They are very penetrating and can only be stopped by hydrogen-rich materials, such as water or paraffin. Fast-moving neutrons are produced by fission reaction in a nuclear reactor. Water is commonly used to moderate and control the speed of neutrons.

電離輻射

電離輻射包括高速粒子及高能量電磁波。它們的高能量可把其他原子內的電子撞出原子之外，產生帶正電荷的離子及帶負電荷的電子。

X 射線是由受激發的電子雲射出，而其他的電離輻射主要是由不穩定原子核在衰變時射出的。以下是各種不同類形電離輻射的簡介：

(1) α 粒子

α 粒子帶正電荷，由兩粒帶正電荷的質子和兩粒中性的中子組成，相等於一個氦原子核。由於帶正電荷，它會受電磁場影響。在自然界內大部份的重元素(原子序數爲 82 或以上)都會在衰變時釋放它，例如鈾和鐳。由於 α 粒子的體積比較大，又帶兩個正電荷，很容易就可以電離其他物質。因此，它的能量亦散失得較快，穿透能力在眾多電離輻射中是最弱的，人類的皮膚或一張紙已能隔阻 α 粒子。

不過如果人類吸入或進食具有 α 粒子放射性的物質，譬如吸入了輻射煙羽，α 粒子就能直接破壞內臟細胞。它的穿透能力雖然弱，但由於它的電離能力很強，它對生物所造成的危害並不下於其他輻射。

(2) β 粒子

β 粒子是高速的電子，由於帶負電荷，會受電磁場影響。它的體積比 α 粒子細得多，穿透能力則比 α 粒子強，需要一塊幾毫米厚的鋁片才可以阻擋它。很多放射性物質都會在衰變時放出 β 粒子。

(3) γ 射線及 X 射線

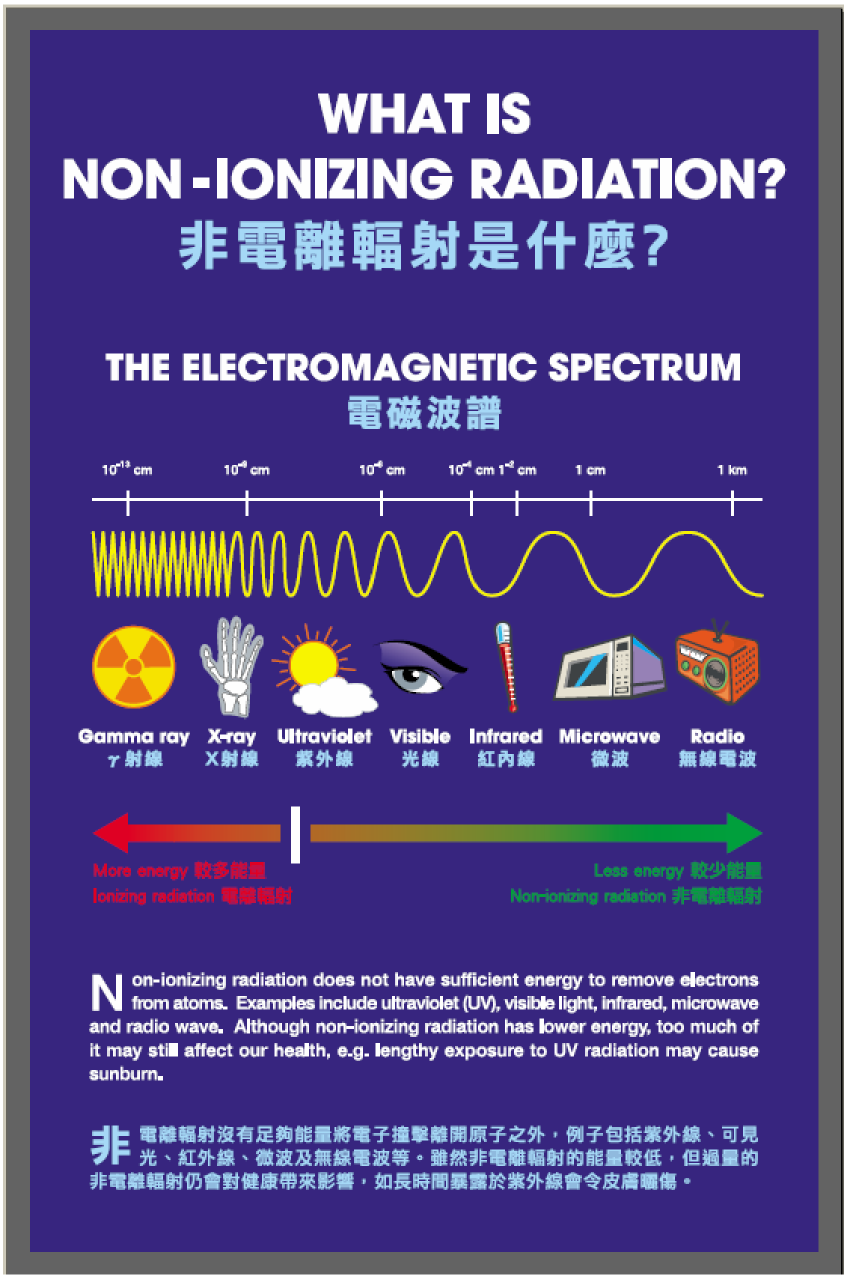
γ 射線及 X 射線都是擁有高能量的電磁波。它們沒有質量，亦不帶電荷，在電磁場內仍然能直線移動。像可見光一樣，它們都是以電磁波形式傳送的能量，不同的是它們的頻率和能量很高，而且穿透能力很強，可以穿過人體，唯有厚厚的鉛板和水泥才可以阻隔它們。

γ 射線及 X 射線相差不遠，主要不同在於它們的輻射源。γ 射線是由不穩定原子核射出的，而 X 射線則由受激發的電子雲射出。

(4) 中子

中子不帶電荷，是組成原子核的粒子之一，穿透能力極高，只有水或石蠟這些含有大量氫原子的物質，可以阻隔中子。核電站的核反應堆中，核裂變會產生高速移動的中子，通常是用水去阻隔及控制中子的移動速度。

Display No. 3
What is non-ionizing radiation?



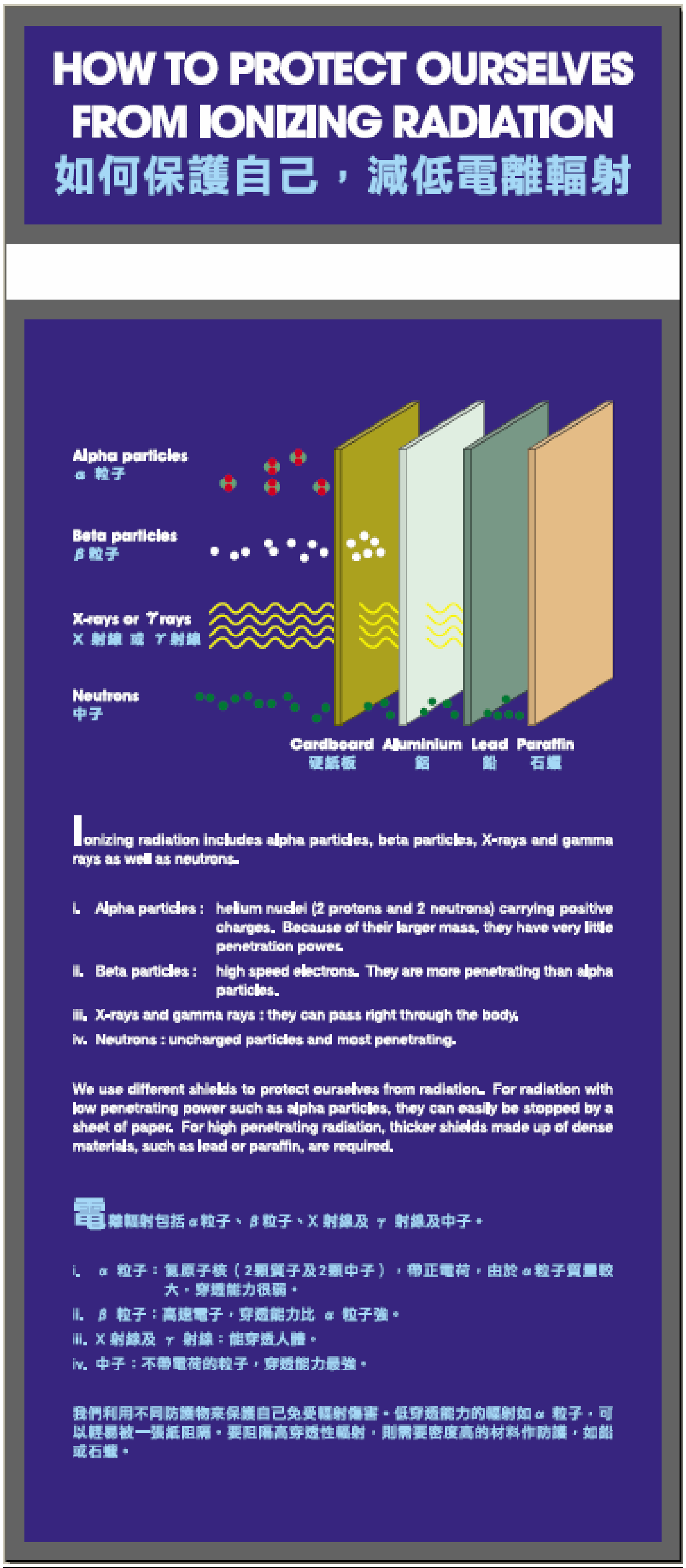
<u>Text of the exhibit</u>

Non-ionizing radiation does not have sufficient energy to remove electrons from atoms. Examples include ultraviolet (UV), visible light, infrared, microwave and radio wave. Although non-ionizing radiation has lower energy, too much of it may still affect our health, e.g. lengthy exposure to UV radiation may cause sunburn.

非電離輻射沒有足夠能量將電子撞擊離開原子之外，例子包括紫外線、可見光、紅外線、微波及無線電波等。雖然非電離輻射的能量較低，但過量的非電離輻射仍會對健康帶來影響，如長時間暴露於紫外線會令皮膚曬傷。

Display No. 4

How to protect ourselves from ionizing radiation?



For reference of teachers only

Text of the exhibit

Ionizing radiation includes alpha particles, beta particles, X-rays and gamma rays as well as neutrons.

i. Alpha particles : helium nuclei (2 protons and 2 neutrons) carrying positive charges. Because of their larger mass, they have very little penetration power.
ii. Beta particles : high speed electrons. They are more penetrating than alpha particles.
iii. X-rays and gamma rays : they can pass right through the body.
iv. Neutrons : uncharged particles and most penetrating.

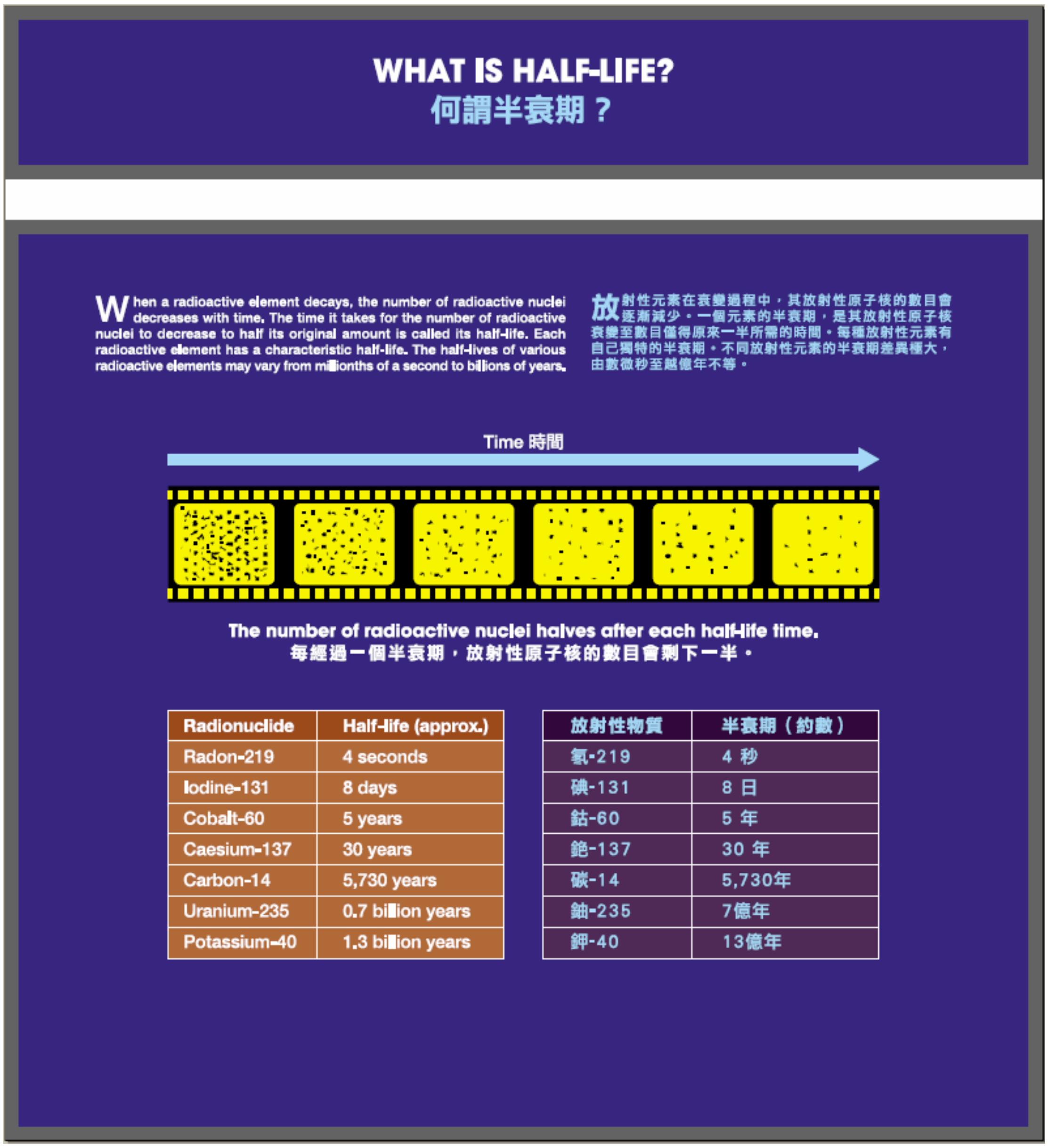
We use different shields to protect ourselves from radiation. For radiation with low penetrating power such as alpha particles, they can easily be stopped by a sheet of paper. For high penetrating radiation, thicker shields made up of dense materials, such as lead or paraffin, are required.

電離輻射包括 α 粒子、β 粒子、X 及 γ 射線及中子。

i. α 粒子：氦原子核(2 顆質子及 2 顆中子)，帶正電荷，由於 α 粒子較重，穿透能力很弱。
ii. β 粒子：高速電子，穿透能力比 α 粒子強。
iii. X 射線 及 γ 射線：能穿透人體。
iv. 中子：不帶電荷的粒子，穿透能力最強。

我們利用不同防護物，來保護自己免受輻射傷害。低穿透能力的輻射如 α 粒子，可以輕易被一張紙阻隔。要阻隔高穿透性輻射，則需要密度高的材料作防護，如鉛或石蠟。

Display No. 5
What is half-life?



Text of the exhibit

When a radioactive element decays, the number of radioactive nuclei decreases with time. The time it takes for the number of radioactive nuclei to decrease to half its original amount is called its half-life. Each radioactive element has a characteristic half-life. The half-lives of various radioactive elements may vary from millionths of a second to billions of years.

放射性元素在衰變過程中，放射性原子核的數目會逐漸減少。一個元素的半衰期，是放射性原子核衰變至剩下來的數目僅爲原來的一半所需時間。每種放射性元素有自己獨特的半衰期。不同放射性元素的半衰期差異極大，由數微秒至越億年不等。

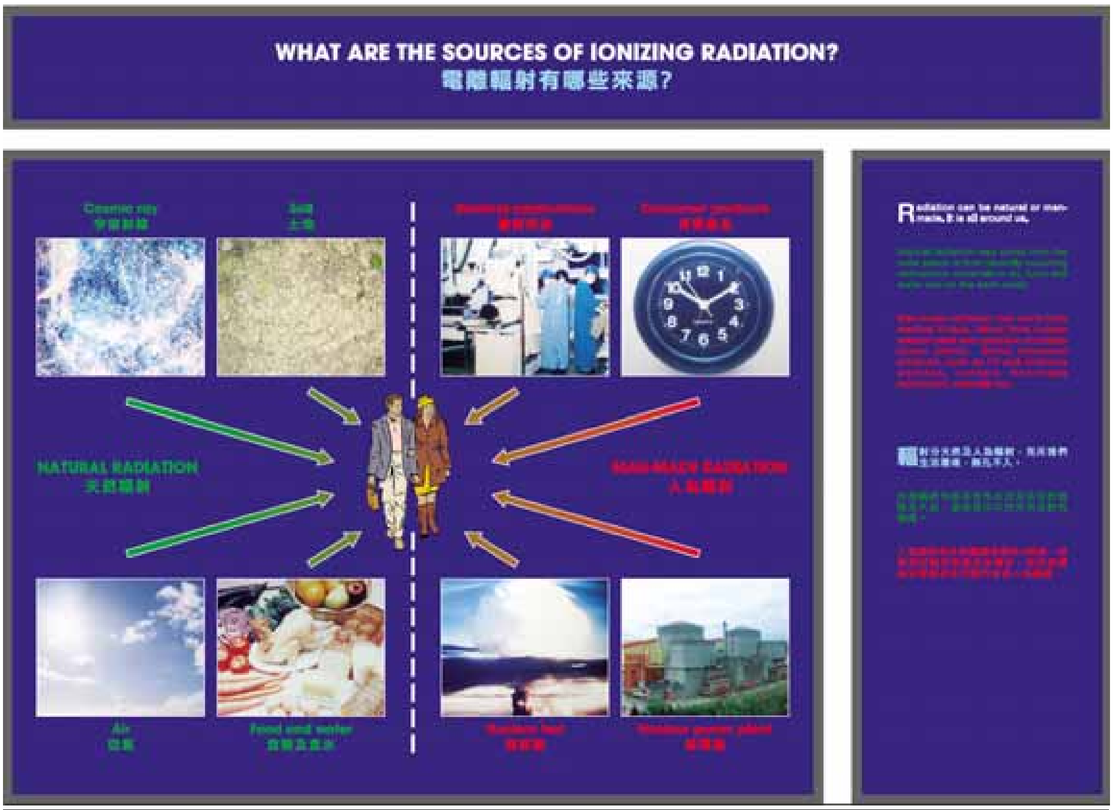
Note to the teacher

The half-life is a convenient quantity which represents how fast a certain radioactive species decays. The longer the half-life, the less likely will a particular nucleus decay, as is the case of U-238. When a particle is emitted from the nucleus, it is attracted by a strong nuclear force. The particle has to overcome this barrier, sometimes called potential barrier, before it can free itself from the nucleus. If the kinetic energy of the particle after the disintegration is nearly equal to the energy height of the potential barrier, then disintegration is likely and the half life is small. The energy of the particle after disintegration can be worked out from the mass-energy relationship by calculating the difference in the mass of the nucleus and its daughter products before and after the disintegration. Results of calculation agree with the observed range of energy of emitted particles and the correlation between the decay rates. This is the basis why radioactive isotopes have probable lives ranging from microseconds to billions of years.

半衰期是一個簡易的數量來表示某一種放射性物質衰變得有多快。有較長半衰期的原子核，就越不容易衰變，例如 U-238。當一個粒子從核心排放出來，它受到一股強大的核力量所吸引，粒子需要克服這個障礙，或稱爲潛在障礙，才能擺脫核心。如果粒子的動能量在衰變後幾乎等同潛在障礙的能量，那麼它就很容易衰變和具有很短的半衰期。粒子在衰變後的能量，可以從質量與能量的關係計算出來，它是衰變之前核心的質量和在衰變之後其子核的質量的差異，計算結果符合排放粒子的能量範圍和衰變率之間的相關性。基於這個因素，放射性同位素的生命可能從微秒到數十億年的時間。

Display No. 6

What are the sources of ionizing radiation?



Text of the exhibit

Radiation can be natural or man-made.   It is all around us.

Natural radiation may come from the outer space or from naturally occurring radioactive materials in air, food and water and on the earth crust.

Man-made radiation may come from medical X-rays, fallout from nuclear weapon tests and operation of nuclear power plants.   Some consumer products, such as TV and luminous watches, contain man-made radioactive materials too.

輻射分天然及人爲輻射，充斥我們生活環境，無孔不入。

天然輻射包括來自外太空及存在於地殼及大氣、食物和水中的天然放射性物質。

人爲輻射有來自醫療診斷的 X 射線、核武器試驗的落塵及核電站。有些消費品如電視、夜光錶都含有人爲輻射。

Note to the teacher

Natural radiation

Radiation is everywhere in our environment. Even our body is also radioactive. We are therefore constantly exposed to different kinds of radiations, especially natural radiation. The annual dose received by the public in Hong Kong from natural background radiation is about 2 mSv. In general, the annual dose received by the public in the world is generally ranged from 1 mSv to 10 mSv (Source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 Report)).

Radionuclides, such as uranium-235, uranium-238, thorium-232 and neptunium-237, have been part of the earth since it came into existence. These radionuclides undergo radioactive decay, by emitting harmful alpha particles, beta particles or gamma rays. Their progenies are also unstable and radioactive. They will undergo radioactive decay until reaching a stable state. The half-lives of uranium-235, uranium-238, thorium-232 and neptunium-237 are 700 million years, 4.5 billion years, 14 billion years and 2.3 million years respectively. Since the half-lives of neptunium-237 and its daughter radionuclides are relatively short comparing to the age of the earth, these radionuclides are not present in the earth nowadays. On the contrary, radionuclides of the uranium-235, uranium-238 and thorium-232 series still exist in our environment. As soil and building materials contain these natural radionuclides, the dose we received therefore depends on the geological composition of the place we live and the building materials we use.

Radon (radon-222) is a major source of natural radiation. It is the decay product of uranium-238 in soil and rocks. Being a gas, part of it escapes from the ground into the atmosphere. If ventilation is poor, radon will accumulate in indoor areas. When we breathe in radon, the alpha particles emitted in the decay process will cause damage to our lung tissue. For the sake of our health, sufficient ventilation is required to reduce the amount of radon in our home.

Another source of natural radiation is cosmic rays from space. Due to the shielding effect of the atmosphere, intensity of cosmic rays increases with altitude. The cosmic rays are mainly made up of high energy protons, plus some helium nuclei and heavy charged particles and ions, with atomic number equal to or greater than 3. When cosmic rays enter the atmosphere, they interact with nitrogen, oxygen and other atoms in the upper atmosphere and produce a large assortment of secondary particles, including radionuclides (such as tritium and carbon-14), neutrons, protons, electrons, mu(μ) and pi(π) mesons and etc. Of them, carbon-14 is commonly used in assessing the age of antiquities.

Radionuclides are also present in our body. Potassium-40, uranium, thorium, radium, carbon-14, tritium and polonium are some examples. Our daily foodstuff consists of trace of radionuclides. These radionuclides will be absorbed through digestion and become part of our body. Meanwhile, their amounts will decrease due to decay or excretion. When the amounts of ingested and excreted radioactive materials reach an equilibrium, a constant level of radiation will be achieved in our body.

Artificial radiation

Artificial radiation has many useful medical and industrial applications. As it may be harmful to health, a lot of research work has been conducted to ensure maximum protection is given to the users of radiation. As a result, our exposure to artificial radiation is much lower than that to natural radiation. Among the exposure pathways, doses due to diagnostic and radiotherapy treatments contribute the largest share.

Patients have to be exposed to radiation during diagnostic imaging, e.g. the x-ray examinations. In imaging of certain organs, some radioactive materials are ingested or injected into the patients. In radiotherapy, dose given to a patient has to be high enough to destroy the tumour.

Nuclear power generation is one of the sources of artificial radiation. During the operation of nuclear power stations, traces of radioactive gases or fluid will be discharged to the environment. Transportation and processing of nuclear wastes will also release traces of radioactive materials. These are also sources of artificial radiation.

Guangdong Nuclear Power Station and Lingao Nuclear Power Station at Daya Bay are located about 50 km from the urban areas of Hong Kong. Their design and operation are strictly in accordance with international safety standards. The risk of any serious nuclear accidents is therefore extremely low.

A number of atmospheric nuclear tests took place from 1945 to 1980. Radioactive particulates produced in the explosions dispersed into the atmosphere by the winds and some of them deposited onto the ground. Deposition of these radioactive materials increased the level of artificial radiation in the environment.

X-ray emission from vacuum tubes of television and video display units are also sources of artificial radiation. Consumer products, such as radioluminous watches and smoke detectors, also consist of radioactive materials.

天然輻射

輻射無處不在，甚至連我們自己的身體都具有放射性。其實我們每日都會接觸到各種各樣的輻射，特別是天然輻射。在本港，平均每人每年吸收的天然本底輻射劑量大約爲 2 毫希沃特。在世界各地，每人吸收的天然本底輻射劑量一般都是由每年 1 毫希沃特到 10 毫希沃特不等 (資料來源：聯合國原子輻射效應科學委員會 (UNSCEAR) 第 2000 年報告)。

地球在誕生時，便存在著天然放射性核素，如鈾-235、鈾-238、釷-232 及鎿-237 等。它們因衰變而產生的子體核素亦屬不穩定及具有放射性。這些子體放射性核素會繼續衰變，直至到達穩定狀態。它們在衰變期間會放出對人體有害的 α 粒子、β 粒子或 γ 射線。鈾-235、鈾-238、釷-232 及 -237 的半衰期分別爲 7 億年、45 億年、140 億年及 2.3 百萬年。由於 -237 及其子體核素的半衰期遠低於地球的年齡，它們現已不存在於地球上。相反，鈾-235、鈾-238 及釷-232 衰變系列的放射性核素仍然存在於我們的生活環境中。地殼土壤及建築材料內，都含有這些天然的放射性核素，因此我們吸收到的天然輻射劑量與所在地區的土質成份有關，亦與我們居所的建築物料有關。

氡氣(特別是氡-222)是一個主要的天然輻射源。氡-222 主要由泥土及岩石中的鈾-238 衰變產生，並從地面散發至大氣中。如室內空氣不流通，散發出來的氡氣會積聚在室內。氡氣在衰變過程中會放出 α 粒子，當我們吸入氡氣時，我們的肺部便會受 α 粒子影響。爲保持健康，我們應該保持室內空氣流通，以免氡氣積聚。

另一個天然輻射來源是來自外太空的宇宙射線。由於大氣層有阻擋宇宙射線的作用，離地面越高，宇宙射線的強度就越強。宇宙射線的主要成份是高能量的質子，其次是氦原子核及少量原子序數 3 或以上的重粒子和離子。宇宙射線進入地球大氣層後，會與大氣高層的氮、氧等原子核發生反應，產生氚、碳-14 等放射性核素及中子、質子、電子、μ 介子、π 介子等次級粒子。

我們的體內亦含有放射性核素。例如鉀-40、鈾、釷、鐳、碳-14、氚、釙等。我們日常吃的食物也含有少量放射性物質，食物被消化後會被身體吸收，成爲身體

的一部份。與此同時這些放射性物質亦會衰變減少或被排出體外。當我們食入和排出的放射性物質達到平衡時，我們體內便維持著一個穩定的輻射水平。

人工輻射

人工輻射在醫學上和工業上都有廣泛用途，由於輻射對人體可能有害，人們在輻射的應用上作了很多研究，盡量在應用過程中保護使用者的安全。所以人們吸收的人工輻射，遠比天然輻射小。而當中以醫療診斷和治療時所引致的劑量佔絕大部份。

在醫療診斷的輻射造影過程中，病人需要接觸輻射。譬如在進行 X 光檢查時，我們需要暴露在 X 射線下。在進行某些器官的造影時，可能需要將放射性物質注入或進食入身體內。放射治療則更加需要足夠的輻射去殺死癌腫瘤。

核能發電亦是人工輻射來源之一。核電站在運作過程中排放出帶有微量放射性的廢氣和廢水，而核廢料在運送或處理過程中亦放出微量放射性物質，這些都是人工輻射的來源。

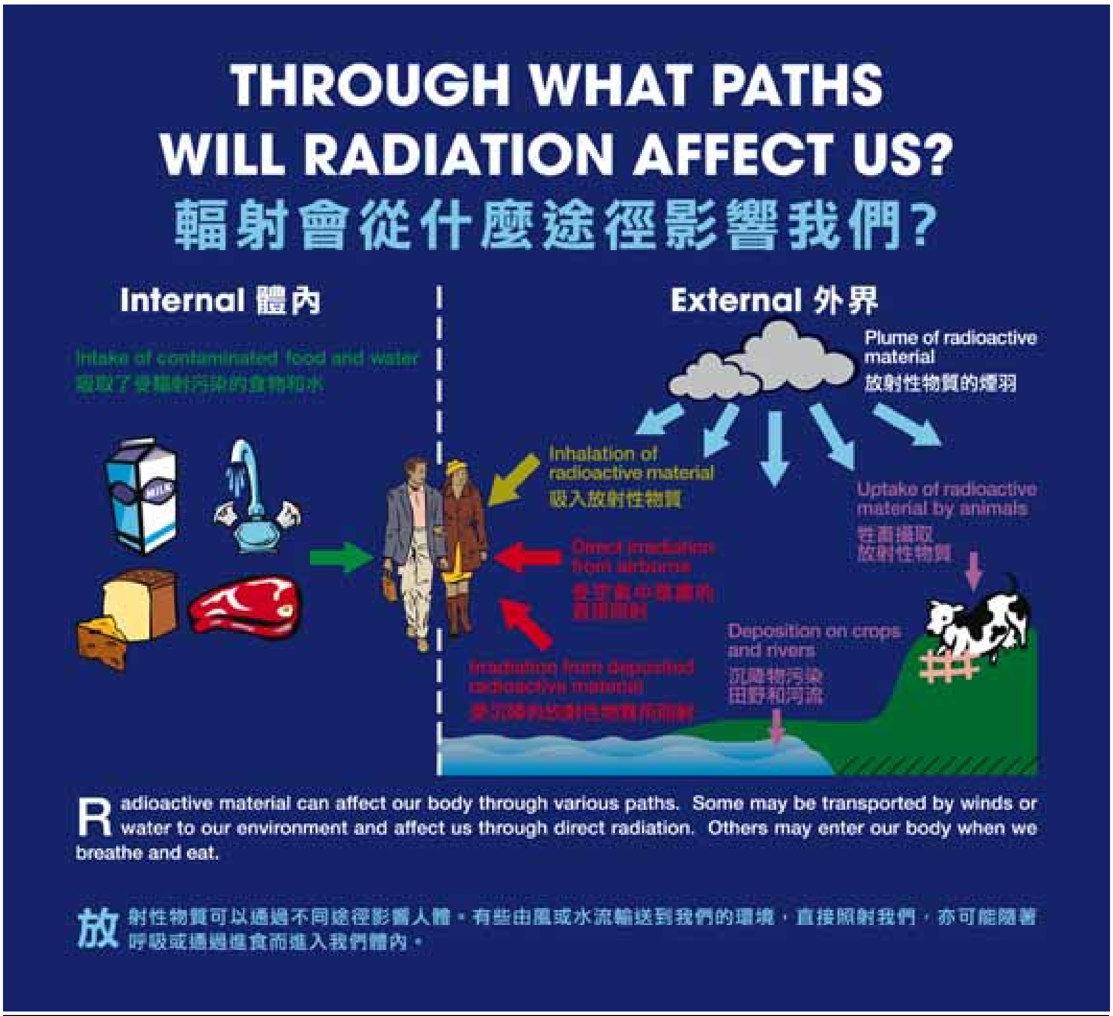
廣東核電站及嶺澳核電站位於大亞灣，距離香港市區約五十公里，它們的設計及運作均嚴格按照國際安全標準。因此，這兩座核電站發生嚴重核事故的機會極低。

在一九四五年至一九八零年期間，世界各地進行了多次大氣核試爆，所產生的放射性塵埃隨風擴散，部份沉降到地上。這些放射性沉積物爲我們自然環境增加了額外的人工輻射。

其他人工輻射來源包括電視機及視象顯示器等，它們的真空管會發放 X 射線。夜光手錶和煙火感應器等消費品中亦含有放射性物質。

Display No. 7

Though what paths will radiation affect us?



Text of the exhibit

Radioactive material can affect our body through various paths. Some may be transported by winds or water to our environment and affect us through direct radiation. Others may enter our body when we breathe and eat.

放射性物質可以通過不同途徑影響人體。有些由風或水流輸送到我們的環境，直接照射我們，亦可能隨著呼吸或通過進食而進入我們體內。

Note to the teacher

In general, we might be affected by radiation through the following two exposure pathways:

1) Plume exposure pathway - inhalation of radionuclides, direct irradiation from airborne or deposited radionuclides.
2) Ingestion pathway - intake of contaminated water or ingestion of contaminated food.

In the unlikely event of a nuclear accident, released radioactive materials behave in the same way as a cloud of smoke called radioactive plume, dispersing into the atmosphere following the winds. Inert gases such as xenon and krypton will travel downwind while diluting rapidly. Some of the volatile substances, such as iodine, caesium and tellurium, will have already condensed into particles by the time they reach the atmosphere. These particles will be deposited on areas affected by the plume with the amount of deposition decreasing with distance. Rainfall will greatly enhance the deposition rate. When radioactive materials deposit onto the ground or into the sea, they will be absorbed by crops, livestock and marine organisms and enter our food chain. We will then be affected by consuming these contaminated crops and livestock.

Hong Kong Observatory has installed an Accident Consequence Assessment System (ACAS). Based on information of the source term and meteorological conditions, the ACAS models the transport and dispersion of the radioactive plume and predicts the associated exposure. Department of Health has also developed a food chain model to simulate exposure pathways in the food chain to determine the effect of radioactive materials on each of our organs.

總體而言，輻射可以透過以下兩種主要途徑影響我們：

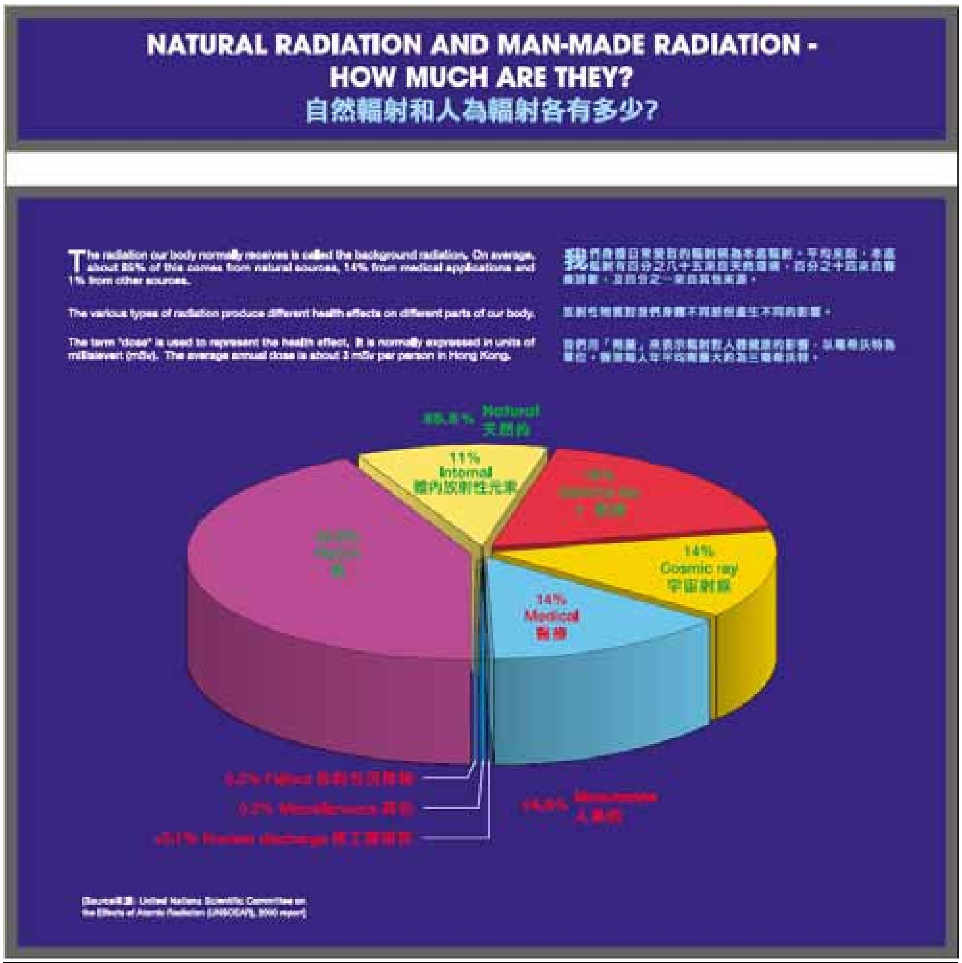
1) 煙羽途徑 - 即直接吸入放射性核素、受到空氣中或沉降在地上的放射性核素直接照射。
2) 食入途徑 - 飲用受放射性物質污染的食水或食用受污染的食物。

萬一核電站發生核事故，洩漏出來的放射性物質會像煙霧般，隨風擴散到各處，稱爲輻射煙羽。氙、氪等惰性氣體會順風移動而迅速稀釋。大部份揮發物，例如碘、銫及碲，在到達大氣層時，已凝結成粒子。這些粒子會在輻射煙羽經過的地區沉降，通常離泄漏源越遠，沉降量越少。而下雨亦可增加沉降率。當放射性物質沉降到地面上或海水中，農作物、牲畜和海洋生物可能會吸收這些放射性物質，而令這些放射性物質進入我們的食物鏈。當我們食用這些受污染的農作物或牲畜時，我們就可能吸收了牠們身上的放射性物質，而受到輻射影響。

香港天文台已設有一套事故後果評價系統，根據源項資料及氣象數據，模擬輻射煙羽在空氣中的擴散情況及預測市民可能受到的輻射煙羽照射。而衛生署亦建立了一個食物鏈模式，模擬放射性物質在食物鏈內的各種照射途徑，從而計算我們身體每個器官可能受到放射性污染物影響的程度。

Display No. 8

Natural radiation and mad-made radiation - How much are they?



Text of the exhibit

The radiation our body normally receives is called the background radiation. On average, about 85% of this comes from natural sources, 14% from medical applications and 1% from other sources.

我們身體日常受到的輻射稱爲本底輻射。平均來說，本底輻射有百分之八十五來自天然環境，百分之十四來自醫療診斷，及百分之一來自其他來源。

The various types of radiation produce different health effects on different parts of our body.

放射性物質對我們身體不同部份產生不同的影響。

The term ‘dose’ is used to represent the health effect. It is normally expressed in units of millisievert (mSv). The average annual dose is about 3 mSv per person in Hong Kong.

我們用「劑量」來表示輻射對人體健康的影響，以毫希沃特爲單位。香港每人年平均劑量爲三毫希沃特。

Note to the teacher

Basic dosimetric quantities

"Absorbed dose" is a physical quantity to measure the radiation energy absorbed by unit mass of substances. Under normal circumstances, the larger the absorbed dose, the larger will be the hazard. Absorbed dose applies to all types of ionizing radiation and substances. For different types of radiation under different exposure conditions, however, the same absorbed dose can cause different biological effects on human bodies.

"Equivalent Dose" and "Effective Dose" are used for assessment of the risk of biological effects produced by ionizing radiation.

1) Absorbed dose

Absorbed dose is one of the fundamental dosimetric quantities in radiation protection. It is a physical quantity to measure radiation energy absorbed by unit mass of materials.

Definition: Energy absorbed per unit mass of the material

Unit: Gray (Gy)

2) Equivalent dose

Biological effects are attributed not only to the absorbed dose but also depend on the type and energy of the radiation. Equivalent dose is a physical quantity to measure the effect to a tissue or organ by different types and energies of radiation.

Definition: For a particular type and energy of radiation, equivalent dose is the absorbed dose averaged over a tissue or organ and weighted for the radiation quality that is of interest. The weighting factor for this purpose is called "radiation weighting factor", which reflects the severity of biological effects due to different types and energies of radiation. When the incident radiation field consists of different types and energies of radiation, the equivalent dose in a tissue or organ is equal to the sum of the weighted absorbed doses.

Unit: Sievert (Sv)

Type of radiation	**Energy of radiation**	**Radiation weighting factor**
Photons	All energies	1
Electrons and muons	All energies	1

Type of radiation	Energy of radiation	Radiation weighting factor
Neutrons	<10keV	5
	10~100keV	10
	>100keV~2MeV	20
	>2MeV~20MeV	10
	>20MeV	5
Protons (except recoil protons)	>2MeV	5
α particles, fission fragments, heavy nuclei	-	20

3) Effective dose

Biological effects also depend on the type of tissue or organ that has been irradiated. Effective dose is to quantify the total detriment from exposures of several organs or tissues.

Definition: Effective dose is the sum of the weighted equivalent doses in all the tissues and organs of the body. The factor by which the equivalent dose in tissue or organ is weighted is called "tissue weighting factor", which represents the relative contribution of that organ or tissue to the total detriment resulting from uniform irradiation of the whole body.

Unit: Sievert (Sv)

Tissue or organ	Tissue weighting factor
Gonads	0.20
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Oesophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surface	0.01
Remainder	0.05

劑量學中常用的量

「吸收劑量」是用來量度電離輻射與物質相互作用時，單位質量物質吸收輻射能量多少的一個物理量。在正常情況下，吸收劑量愈大，危害亦愈大。吸收劑量適用于任何類型的電離輻射和任何物質。由於輻射類型和照射條件等不同，相同的吸收劑量可能產生完全不同的生物效應。

「當量劑量」及「有效劑量」是評價產生生物效應的危險時常用的劑量學量。

1) 吸收劑量

吸收劑量是輻射防護劑量學中的一個基本量。它是量度物質受到電離輻射照射後，吸收能量多少的一個物理量。

定義：單位質量物質吸收的電離輻射能量。

單位：戈瑞，簡稱戈，其符號爲 Gy。

2) 當量劑量

輻射對人體的影響除了與吸收劑量有密切關係外，還與電離輻射的種類及其能量有關。當量劑量是量度不同種類及能量的輻射，對人體個別組織或器官造成的影響的一個物理量。

定義：特定種類及能量的輻射在一個組織或器官中引致的當量劑量，就是該輻射在組織或器官的平均吸收劑量乘以該輻射的權重因子。這個權重因子稱爲「輻射權重因子」，它反映不同種類及能量的輻射對人體產生不同程度的影響。當輻射有多個種類和能量時，在一個組織或器官的當量劑量就是個別輻射所致的當量劑量之和。

單位：希沃特，簡稱希，符號爲 Sv。

輻射種類	輻射能量	輻射權重因子
光子	所有能量	1
電子和介子	所有能量	1
中子	<10keV	5
	10~100keV	10
	>100keV~2MeV	20
	>2MeV~20MeV	10
	>20MeV	5
質子(反沖質子除外)	>2MeV	5
α 粒子、裂變碎片、重核	-	

3)　有效劑量

當人體受到電離輻射照射時，同一個當量劑量對不同器官或組織有不同的效應。有效劑量是表示在多個器官或組織同時受照時，輻射對人體的總危害。

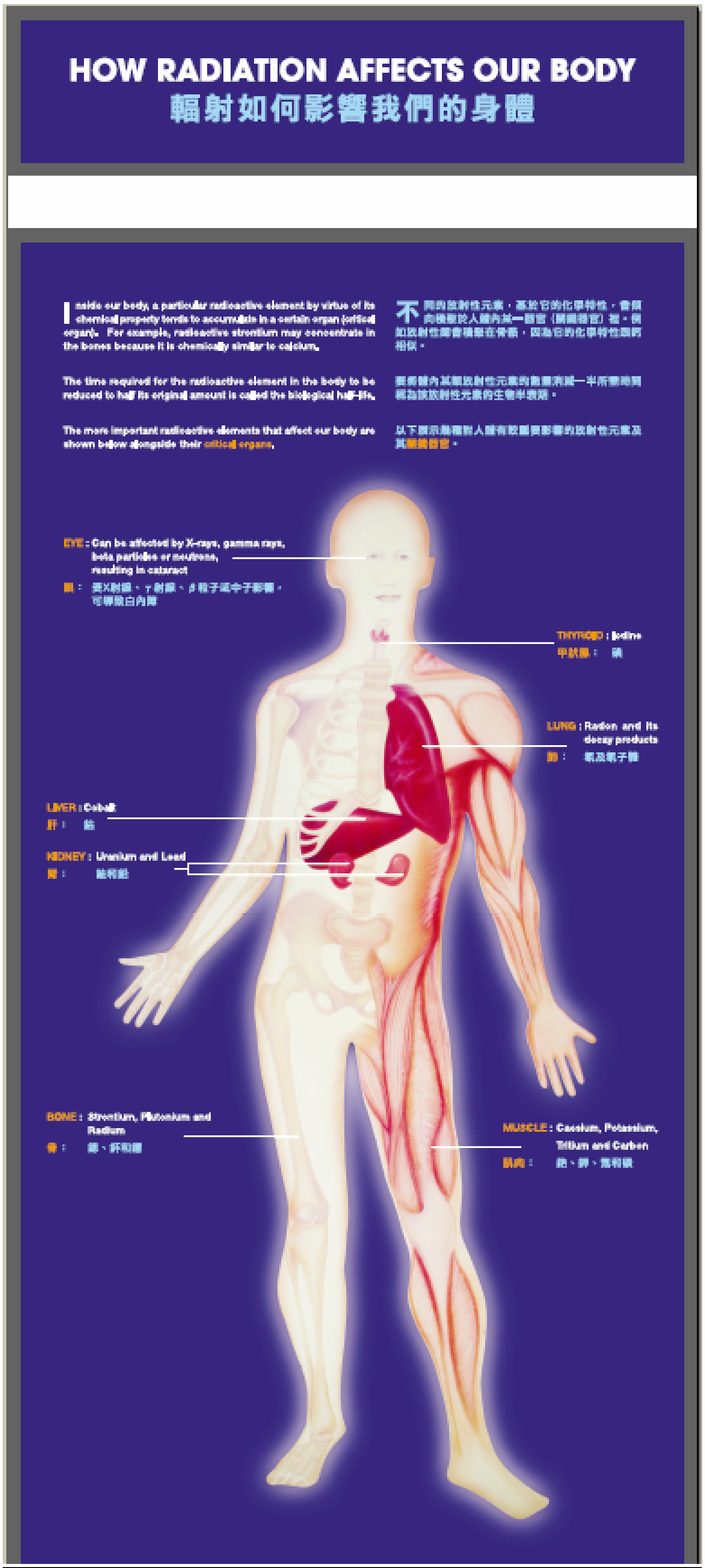
定義：體內所有組織與器官經加權後的當量劑量之和。這個權重因子稱爲「組織權重因子」，它反映在全身均勻受照下各組織或器官對總危害的相對貢獻。

單位：希沃特，簡稱希，符號爲 Sv。

組織或器官	組織權重因子
性腺	0.20
紅骨髓	0.12
結腸	0.12
肺	0.12
胃	0.12
膀胱	0.05
乳腺	0.05
肝	0.05
食道	0.05
甲狀腺	0.05
皮膚	0.01
骨表面	0.01
其餘器官	0.05

Display No. 9

How radiation affects our body?



For reference of teachers only

Text of the exhibit

Inside our body, a particular radioactive element by virtue of its chemical property tends to accumulate in a certain organ (critical organ). For example, radioactive strontium may concentrate in the bones because it is chemically similar to calcium.

The time required for the radioactive element in the body to be reduced to half its original amount is called the biological half-life.

The more important radioactive elements that affect our body are shown below alongside their critical organs.

不同的放射性元素，基於它的化學特性，會傾向積聚於人體內某一器官 (關鍵器官) 裡。例如放射性鍶會積聚在骨骼，因爲它的化學特性跟鈣相似。

要將體內某類放射性元素的數量消減一半所需時間稱爲該放射性元素的生物半衰期。

以下展示幾種對人體有較重要影響的放射性元素及其關鍵器官。

Note to the teacher

The retention of radionuclides in the human body depends on their movement in the body. After intake via the gastro-intestinal tract or through breathing, insoluble radionuclides will only slowly enter the bloodstream or the lymphatic system. Any particles entering the systemic circulation will end up in the liver, spleen and red bone marrow. Here they may remain for up to the life-span of the individual. If the radionuclides are soluble, they readily enter the blood-stream and accumulate in a certain organ depends upon their chemical characteristics. Some examples are given below:

1) Tritium (H-3)

   Tritiated water taken orally is rapidly absorbed from lung and the gut. It distributes throughout the body water and is subsequently excreted in the urine, sweat, faeces and via the lungs with a biological half-time of about 12 days (i.e. about 5.8% of total body water is lost per day). The loss of tritiated water can be increased by increasing the fluid intake.

2) Caesium (Cs)

   The first observation of the presence of fallout Cs-137 in man was reported in

1956. Since then it has been shown to be present in everyone as a result of contamination of the environment by nuclear test explosions. Cs-137 may enter the body either by inhalation or through the food chains. Absorption by the gut is almost 100% and is rapidly taken up by cells. At equilibrium the muscle accounts for more than 50% of the total body casesium and bone about 8%. The biological half-time of Cs in man varies from 2 and 100 days.

3) Iodine (I)

Iodine deposits mainly in the thyroid gland in the neck region. Iodide or elemental radioactive iodine may be ingested or the volatile compounds inhaled. The iodide that is synthesized into hormone leaves the gland with a half-life of about 80 days (for adult) and enter other tissues, from this source most of the iodine (about 80%) is metabolized back to free iodide with a half-life of about 8 days and re-enters the iodide space, the rest is excreted. In adults, the total excreted is approximately equal to the amount absorbed. Because of recycling the apparent biological half-life in the gland is about 120 days.

4) Radium (Ra)

After ingestion about 20% of radium is absorbed. Most of that absorbed is excreted within a few days, mostly in the faeces, and by a week, only about 10% of that entering the blood remains in the body. The radium retained is almost entirely deposited in the skeleton. Little can be done to remove radium that is deposited in the bone.

5) Strontium (Sr)

About 30% of strontium that is ingested is absorbed into the blood. By about 10 days after entry into the blood about 19% has deposited in the skeleton and 14% in soft tissues. By 3 years the skeleton retain about 98% of the total body activity.

6) Plutonium (Pu)

The main route of entry of plutonium into the body is by inhalation although it can also enter through cuts and wounds. After inhalation, deposition in the lungs is determined by particle size. Clearance from the lungs depends upon its chemical form. Whatever the chemical form inhaled, a fraction consisting of any soluble materials (or particles less than 1 nm) will be rapidly transported to blood and this excreted through the kidneys or deposited in tissues (mainly ins skeleton and liver). Larger particles, mostly in the form of polymer, or particles that are insoluble are retained in the lungs and may be taken up by scavenger cells. Alternatively, it may gradually dissolve in lung fluids and translocate to blood. Lung retention half-times may vary from 100 to 1000 days, soluble compounds being cleared more rapidly than insoluble compounds. Of activity entering the blood about 45% deposits in the liver, 45% in the skeleton and the remaining 10% is either excreted or deposited in other tissues. Retention half-times in bone and liver are estimated to be 100 years and 40 years respectively. Those deposited in the gonads are retained indefinitely.

放射性核素在人體內的去留取決於核素在體內的移動情況。經腸道進入或通過呼吸攝入體內後，不溶性放射性核素只會慢慢地進入血液或淋巴系統，任何粒子進入體內循環系統最終將停留在肝、脾和紅骨髓，它們可能留在這裡直至生命終結。可溶性放射性核素會迅速進入血液，並隨其化學特性停留在人體某一器官裡。以下列出一些例子：

1）氚（H3）

口服入的氚水迅速被肺和腸吸收。它遍佈整個身體的水分，之後隨著尿液，汗水，糞便和通過肺部排出體外，其生物半衰期約爲 12 天（即每天約失去身體總水分的 5.8%），攝入更多液體可以加快排出氚水。

2）銫（Cs）

在 1956 年首次發現人體裡存在銫-137，由於核試驗爆炸污染環境，銫-137 自此以後一直存在於每個人內。銫-137 可以通過吸入或食物鏈進入人體，它幾乎 100%被腸吸收，並且立刻進入細胞。在平衡狀態下，人體內的銫-137 有 50%以上留在肌肉，而有約 8%留在骨骼中。銫積聚在人體裡的生物半衰期約爲 2 至 100 天。

3）碘（I）

碘主要沉積在頸部甲狀腺內。碘化物或放射性碘元素可從進食或吸入揮發性化合物進入體內。碘轉爲激素在成人腺內的半衰期大約爲 80 天，隨之進入其他組織。大部分碘（約 80%）以約 8 天的半衰期經新陳代謝回復爲自由碘，重新進入碘化空間，其餘的被排泄出體外，成年人的總排出量約等於吸收的。由於再循環效果，碘在腺內的生物半衰期似是 120 天。

4）鐳（Ra）

大約 20%攝入的鐳會被吸收，其中多數在幾天之內被排泄出體外，主要是在糞便。在一個星期後，只有約 10%進入血液的鐳仍然留在體內，幾乎全部積

聚在骨骼，消除沉積在骨骼的鐳是很困難的。

5）鍶（Sr）

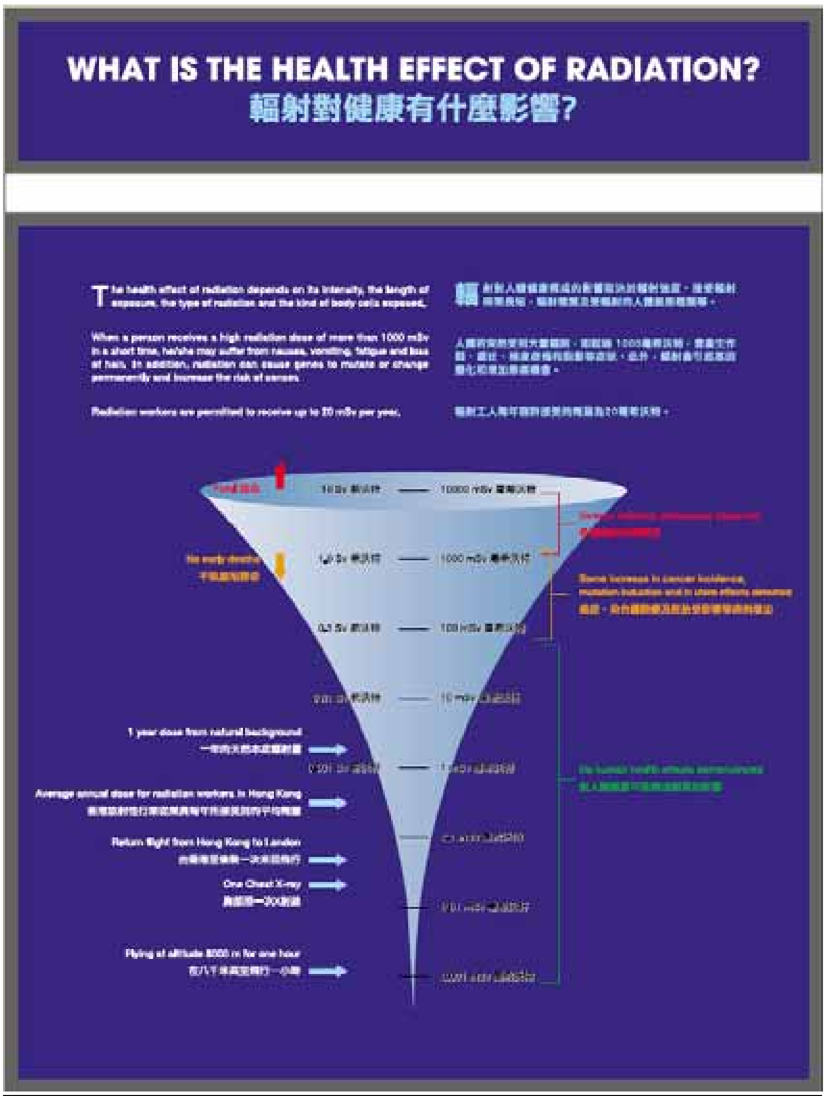
大約 30%攝入的鍶會進入血液，大約 10 天後，約 19%會沉積在骨骼和 14%在軟組織。3 年後，全身約 98%的鍶仍然積聚於骨骼內。

6）鈈（Pu）

鈈主要由呼吸進入人體，亦可以通過傷口和創傷攝入鈈。吸入體內的鈈會否沉積在肺部取決於粒子的大小，而能否離開肺部則取決於其化學性質。無論是以什麼化學形態進入人體，小部分包括可溶性物質（或粒子小於 1 納米）將迅速運送到血液和通過腎臟排泄或沉積在組織內（主要是集骨骼和肝臟），較大的粒子，主要是聚合物或不溶性粒子，它們會停留在肺部或被清除細胞掃除。另外，它可能會逐漸溶解在肺內液體，並轉到血液。鈈在肺的半衰期可以從 100 到 1000 天，可溶性化合物比不溶性化合物更快清除。約 45%進入血液的鈈停留在肝臟中，有 45%在骨骼，其餘的 10%被排出或存在其他組織。留在骨骼及肝臟的半衰期估計分別是 100 年和 40 年，那些積聚在性腺會永遠保留下去。

Display No. 10

What is the health effect of radiation?



Text of the exhibit

The health effect of radiation depends on its intensity, the length of exposure, the type of radiation and the kind of body cells exposed.

輻射對人體健康構成的影響取決於輻射強度、接受輻射時間長短、輻射種類及受輻射的人體細胞種類等。

When a person receives a high radiation dose of more than 1000 mSv in a short time, he/she may suffer from nausea, vomiting, fatigue and loss of hair. In addition, radiation can cause genes to mutate or change permanently and increase the risk of cancer.

人體若突然受到大量輻照，即超過 1000 毫希沃特，會產生作悶、嘔吐、極度疲倦和脫髮等症狀。此外，輻射會引起基因變化和增加患癌機會。

Radiation workers are permitted to receive up to 20 mSv per year.

輻射工人每年容許劑量爲 20 毫希沃特。

Note to the teacher

Health effect of ionizing radiation

The radiation affects human body in highly complicated processes. Various degrees of biological effects, from damage to death of living tissues, involve a number of pathological changes in human cells.

When exposed to ionizing radiation, large molecules such as nucleus acid and proteins in the cells will be ionized or excited. This may cause changes in the molecular structures which then affect the function and metabolism of the cells. Laboratory experiments have demonstrated that ionizing radiation can cause breakage of the DNA chain or can deter cell replications. In addition, the production of harmful free radicals (e.g. OH^{-1}, H^{+} etc.) by the ionization of water molecules due to radiation may lead to changes in molecules that are biologically important for the functioning of cells.

Although radiation can cause damage to living tissues, human cells however can repair the damage through natural metabolic processes if the absorbed dose is not high. Recovery of cells depends on the degree of initial damage and may be different for different individuals.

Generally speaking, the biological effects of ionizing radiation can be classified according to the characteristics of effects, occurring times and the object that shows the effects.

Characteristic of effects	**Occurring time**	**Object**	**Effects on organs**
Deterministic Effects	Acute Effects	Somatic Effects	Skin damage Damage of reproductive system Damage of blood forming system Damage of digestive system Damage of central nervous system
	Latent Effects		Cataract Damage of immunization system
Stochastic Effects			Cancer
		Genetic Effects	Heredity effects

輻射對人體健康的影響

輻射對人體的作用是一個極其複雜的過程。人體從吸收輻射能量開始，到產生生物效應，乃至機體的損傷和死亡爲止，涉及許多不同性質的變化。

在輻射的作用下，人體內的生物大分子，如核酸、蛋白質等會被電離或激發。這些生物大分子的性質會因此而改變，細胞的功能及代謝亦遭到破壞。實驗證明輻射可令 DNA 斷裂或阻礙分子複製。此外，人體內的生物大分子存在於大量水分子中，當輻射作用於水分子時，水分子亦會被電離或激發，產生有害的自由基(如 OH^{-1}、 H^{+} 自由基等)，繼而使在水分子環境中的生物大分子受到損傷。

雖然輻射可能對人體造成損傷，但如劑量不高，機體可以通過自身的代謝過程對受損傷的細胞或局部組織進行修復，這種修復作用程度的大小，既與原初損傷的程度有關，又可能因個體間的差異而有所不同。

一般來說，因輻射照射而產生的生物效應，可按照效應發生的規律、出現的時間或出現的對象來分類:

<table>
<tr><th>按效應發生規律分類</th><th>按效應出現的時間分類</th><th>按效應出現的對象分類</th><th>機體變化</th></tr>
<tr><td rowspan="2">確定性效應</td><td>近期效應</td><td rowspan="3">軀體效應</td><td>皮膚損傷
生育器官損傷
造血器官損傷
消化器官損傷
中樞神經損傷</td></tr>
<tr><td rowspan="3">遠期效應</td><td>白內障
免疫系統受損</td></tr>
<tr><td rowspan="2">隨機性效應</td><td>癌病</td></tr>
<tr><td>遺傳效應</td><td>遺傳病</td></tr>
</table>

Display No.11
Working out your radiation dose

Text of the exhibit

Radiation is present everywhere. It can be natural or man-made. The world average background radiation dose is about 3 mSv per year per person. It varies from place to place and depends on the life style.

輻射一直存在於我們的生活中，包括天然或人爲輻射。全球平均的本底輻射劑量每人每年約 3 毫希沃特。 所受到的本底輻射劑量一般視乎地點及生活習慣而有所變化。

This game helps you estimate your annual radiation dose.

本遊戲可助你估算一年裏所接受的本底輻射劑量。

Note to the teacher

Visitors can interact with the computer by answering the questions (related to the every day life activity) raised by the computer. The computer will immediately work out the radiation dose corresponding to that activity and sum up for you the to total annual radiation dose you would have received as a result of the daily activities that are characteristics of your living habit.

參觀者可以互動形式回答電腦提出的問題（關於每天生活的活動）。電腦將立即計算出相應於該活動的輻射劑量，並按照您的生活習慣，總結你全年由於日常活動會接收到的總輻射劑量。

Display No.12

What are the uses of radiation?

Text of the exhibit

Proper use of radiation can improve our lives. Examples include

i. electricity generation such as nuclear power plant
ii. medical application such as X-ray imaging
iii. industrial application such as welding and food preservation
iv. consumer products such as luminous signs

善用輻射可改善人類生活，例子包括

i. 發電如核電廠
ii. 醫學用途如 X 光圖像
iii. 工業用途如焊接及食物保存
iv. 消費品如螢光指示牌

Note to the teacher

Radiation is part of our daily life. We benefit from it without noticing its presence. Common examples are electricity generation, medical and industrial applications. With proper use, radiation can be beneficial to the society.

1) Electricity generation

The demand for energy increases with the world's booming population and expanding economy. We are consuming energy at a pace much faster than it can be replenished. Nuclear energy is one of the solutions to meet this ever increasing demand of energy. To date, there are about 440 commercial nuclear power reactors around the world, mainly relying on splitting, or fissioning, of uranium or plutonium nuclei. These reactors generate about 17% of the electricity world-wide.

Guangdong Nuclear Power Station and Lingao Nuclear Power Station at Daya Bay are located some 50 km to the northeast of Hong Kong. They began commercial operation in February 1994 and May 2002 respectively. Both stations use pressurized water reactors to generate power for the people of Hong Kong and Guangdong.

2) Medical applications

Many of us are aware of the widespread use of radiation in the medical community. It can be used for diagnosis as well as therapy for a number of diseases.

In diagnostic treatments, x-rays can provide images for identifying abnormal changes in body organs and tissues. With advanced imaging and computing technologies, a three dimensional picture or animation can be generated to facilitate the diagnostic treatment if radioisotopes are injected or ingested into the patient. The most widely used diagnostic radioisotope is technetium-99m which has a half-life of six hours and releases γ rays during radioactive decay. While giving the patient a very low radiation dose, technetium-99m allows sufficient time for the diagnosis process.

In therapy treatments, a radioisotope of iodine, iodine-131, is used to treat thyroid cancer. For some cancers, γ rays from cobalt-60 sources are used to destroy cancer cells. Irradiating a tumour with ionizing radiation has proved to be effective in inhibiting the tumour's growth or even destroying it.

Nowadays, many medical utensils are sterilized by γ rays from cobalt-60 sources. This technique is much cheaper and more effective than steam sterilization. Disposable syringe, cotton wool and surgical consumable are good examples. Since it is not a high temperature treatment process, it can be used to sterilize a range of heat-sensitive items such as plastics. In addition, as γ rays have very high penetrating power, the sterilization process can be done after the item is packaged. This ensures that the item is free from bacteria before being used.

Since the discovery of anthrax-laden mail in US in October 2001, US Government uses x-rays in the same manner as in medical usage to sterilize suspected items sent through mail to avoid panic in the country.

3) Industrial and agricultural applications

In industrial applications, γ rays with high penetrating power are used to image defects in welds and metal castings. In addition, radiation is widely used in automatic quality control systems in production lines, such as to gauge fluid level in beverage cans or density of tobacco in cigarettes. It is also used to measure the thickness of electroplates and to eliminate static charges in industries.

In agricultural applications, radioisotopes are usually used as tracers. Fertilizers doped with radioisotopes provide a means to find out the amount of fertilizer uptaken by crops and the portion that is lost. In addition, radiation can be used to exterminate insects. Sterile Insect Technique (SIT) is applied to inhibit the reproducing power of the insects so as to reduce their population. The SIT operations conducted in Mexico were successful in reducing the number of pest/insects significantly. With the support of the United Nations Food and Agriculture Organisation (FAO) and the International Atomic Energy Agency (IAEA), the SIT programmes are underway in a number of countries.

4) Applications in consumer products

Radioactive materials are used in some consumer products. With suitable safety design and under appropriate use, their benefits significantly outweigh the associated radiation risks. These products include smoke detectors, luminous signs, radioactive lightning conductors, etc.

Smoke detector

5) Archaeological applications

Antiquities can be dated by measuring their natural radioactivity. Popular techniques include "carbon-14 dating" and "thermoluminescence dating". They are useful tools in geological, anthropological and archaeological researches.

Carbon-14 is produced when cosmic rays bombard the atmosphere. The carbon-14 formed will be oxidized to carbon dioxide and absorbed by plants. Meanwhile, animals will ingest plants and hence most of the organic materials contain a certain amount of carbon-14. As soon as the plants or animals die, the uptake of carbon-14 will cease and the amount of carbon-14 will decrease with time due to radioactive decay. The half-life of carbon-14 is about 5,730 years. By measuring the amount of carbon-14 in the ancient organic materials, we can estimate the time when the organism died.

Trace amounts of natural radioactive materials, such as uranium, thorium and potassium with half-lives of up to one billion years, exist in soil. When the inorganic crystal in clay is irradiated by the above radioactive materials, part of the radiation will be released in the form of light and the rest will be trapped in the crystal. When such crystal is heated, the stored energy will be released as light, the so called thermoluminescence effect. Thermoluminescence dating can be used to determine how much time has elapsed since the last time the object was heated. The older the object, the more light will be released. Thermoluminescence dating is commonly used to determine the age of pottery

輻射與我們息息相關，很多時我們不知不覺間已經享用到輻射應用所帶來的好處。無論在發電、醫療、工業方面，輻射的應用都多不勝數。只要運用得宜，輻射也可以造福社會。

1) 發電

隨著世界人口不斷膨脹及經濟增長，人們對能源的需求日益增加。我們消耗能源的速度，遠超過地球所能負擔，核能是解決能源需求日增的其中一個方法。目前世界各地的核能發電反應堆有大約四百四十個，供應全球所需電力的約百分之十七。這些發電廠主要利用鈾或 的原子核分裂而發電。

位於香港東北面約五十公里的廣東核電站和嶺澳核電站已分別於一九九四年二月及二零零二年五月投產。兩座核電站均使用壓水式反應堆，生產的電力供應給香港及廣東一帶地區使用。

2) 醫學用途

輻射在醫療上的用途爲人所熟識，它可以協助醫生診斷及治療多種疾病。

在診斷方面，X 射線可用來判斷身體器官和組織的異常變化。運用現時先進的造影技術及電腦科技，只要我們將放射性同位素注入或進食入病人體內，就可以產生立體或動態的影像，從而研究病人的情況。常用的放射性同位素爲鎝-99m，它的半衰期爲六小時，在衰變過程中放出 γ 射線。它的輻射劑量安全之餘，亦能提供足夠的時間進行診斷。

在治療方面，放射性同位素碘-131 用於醫治甲狀線癌；在治療某幾種癌症時，亦會利用鈷-60 所放出的 γ 射線，射入人體內，將癌細胞殺死。事實證明，放射治療有效抑制腫瘤生長，甚至能將癌症根治。

現今很多醫療用品都利用鈷-60 所放出的 γ 射線進行消毒。這種消毒程序比用蒸氣消毒更有效及便宜。用完即棄的針筒、棉花、手術用品就是很好的例子。由於不需經過高溫處理，很多會被高溫破壞的物料，例如塑膠等，都可以使

用放射程序消毒。加上 γ 射線有穿透能力，物件可以在包裝封密後才進行消毒，確保物件在解封前不會受到細菌污染。

二零零一年十月期間，在美國發現了炭疽菌郵件後，美國政府亦是利用 X 射線，為可疑的郵件消毒，以免炭疽菌在美國引起恐慌，其消毒的原理亦是一樣。

3) 工業及農業用途

在工業方面，γ 射線穿透力特強，可用作探測焊接點和金屬鑄件的裂縫。另外，在工業生產線上的自動品質控制系統，例如測檢罐裝飲品內的飲料高度或香煙的煙草密度等，都廣泛應用了輻射。輻射更可用於量度電鍍薄膜的厚度，也可用於消除靜電。

在農業方面，放射性同位素經常被用作追蹤劑。將放射性物質加入肥料中，然後量度農作物的放射性，便可以知道有多少肥料被吸收，及有多少流失。輻射亦可供滅蟲之用。Sterile Insect Technique (SIT) 可以令昆蟲失去繁殖能力，從以減少牠們的數目。墨西哥運用了這種方法，成功地把害蟲的數目大大減少。在聯合國食物及農業組織 (FAO) 及國際原子能機構 (IAEA) 的協助下，這個計劃正在多個國家進行

4) 消費品用途

有些用品，如煙火感應器、螢光指示牌和避雷針等都包含放射性物質。通過合適的設計和適當的使用，輻射的好處其實遠遠大於其所引起的危害。

煙火感應器

5) 考古用途

透過量度古物內天然放射性物質的濃度，我們可以鑑定古物所屬的年代，常用的技術包括「碳-14 定年法」和「熱釋光定年法」，對地質學、人類學及考古學的研究都有莫大的幫助。

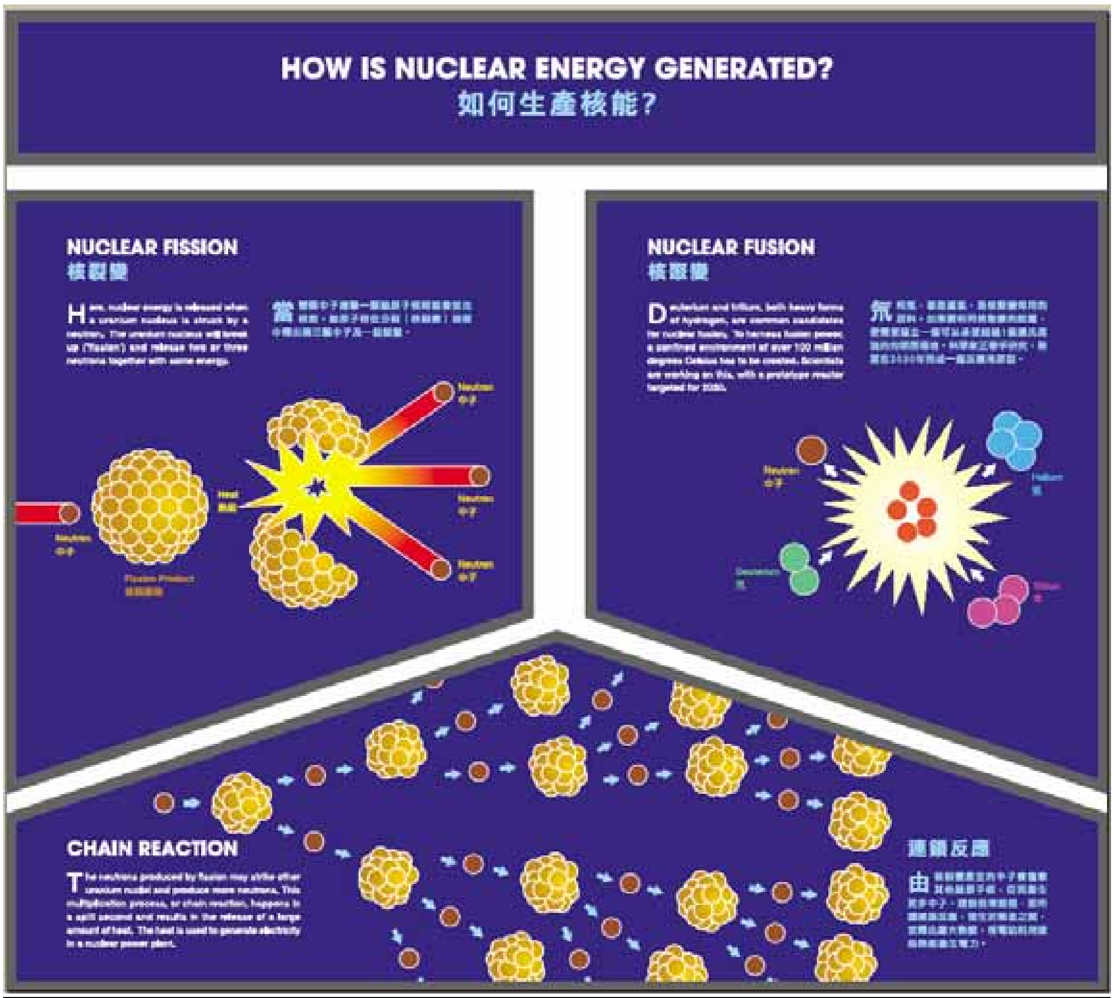
碳-14 是因宇宙射線撞擊地球大氣層而產生的，碳-14 氧化成二氧化碳後會被植物吸收。同時，動物又會進食植物，所以大部份有機體都會有一定份量的

碳-14。但當植物和動物死去，他們便會停止吸取碳-14。碳-14 的份量因衰變會隨時間而減少，每經過一個半衰期(即大約 5,730 年)，含量便會減半。透過量度古代有機體的碳-14 含量，我們便可以估計該有機體的死亡年份。

泥土中含有微量的鈾、釷和鉀等天然放射性物質，這些放射性同位素的半衰期可以長達 10 億年。同時，粘土中又含有各種無機晶體和礦物質。當無機晶體受到上述放射性物質照射後，一部份輻射能量會令晶體發熱，另一部分能量則貯藏在晶體中。如果晶體被加熱， 部份能量會以可見光的形式釋放出來，這種現象叫做熱釋光現象。熱釋光定年法可判斷古物距離最近的一次加熱的時間，古物發出的熱釋光越強，年代就越遠，反之，則屬較近期。熱釋光定年法常被用作判斷陶器的年代。

Display No. 13

How is nuclear energy generated?



Text of the exhibit

Nuclear Fusion

Deuterium and tritium, both heavy forms of hydrogen, are common candidates for nuclear fusion. To harness fusion power, a confined environment of over 100 million degrees Celsius has to be created. Scientists are working on this, with a prototype reactor targeted for 2030.

核聚變

氘和氚，都是重氫，是核聚變常用的原料。如果要利用核聚變的能量，便需要建立一個可以承受超過 1 億攝氏高溫的的禁閉環境。科學家正著手研究，期望在 2030 年完成一座反應堆原型。

Nuclear Fission

Here, nuclear energy is released when a uranium nucleus is struck by a neutron. The uranium nucleus will break up ('fission') and release two or three neutrons together with some energy.

核裂變

當壹顆中子撞擊一顆鈾原子核時就會放出核能。鈾原子核在分裂(核裂變)過程中釋出兩三顆中子及一些能量。

Chain Reaction

The neutrons produced by fission may strike other uranium nuclei and produce more neutrons. This multiplication process, or chain reaction, happens in a split second and results in a release of a large amount of heat. The heat is used to generate electricity in a nuclear power plant.

連鎖反應

由核裂變產生的中子會撞擊其他鈾原子核，從而產生更多中子。這個倍增過程，即所謂連鎖反應，發生於瞬息之間，並釋出龐大熱能。核電站利用這些熱能產生電力。

Display No. 14
Which fuel is more energy efficient?

Text of the exhibit

One uranium pellet (about 1 cm in diameter and 1.5 cm in length) generates the same amount of energy as:

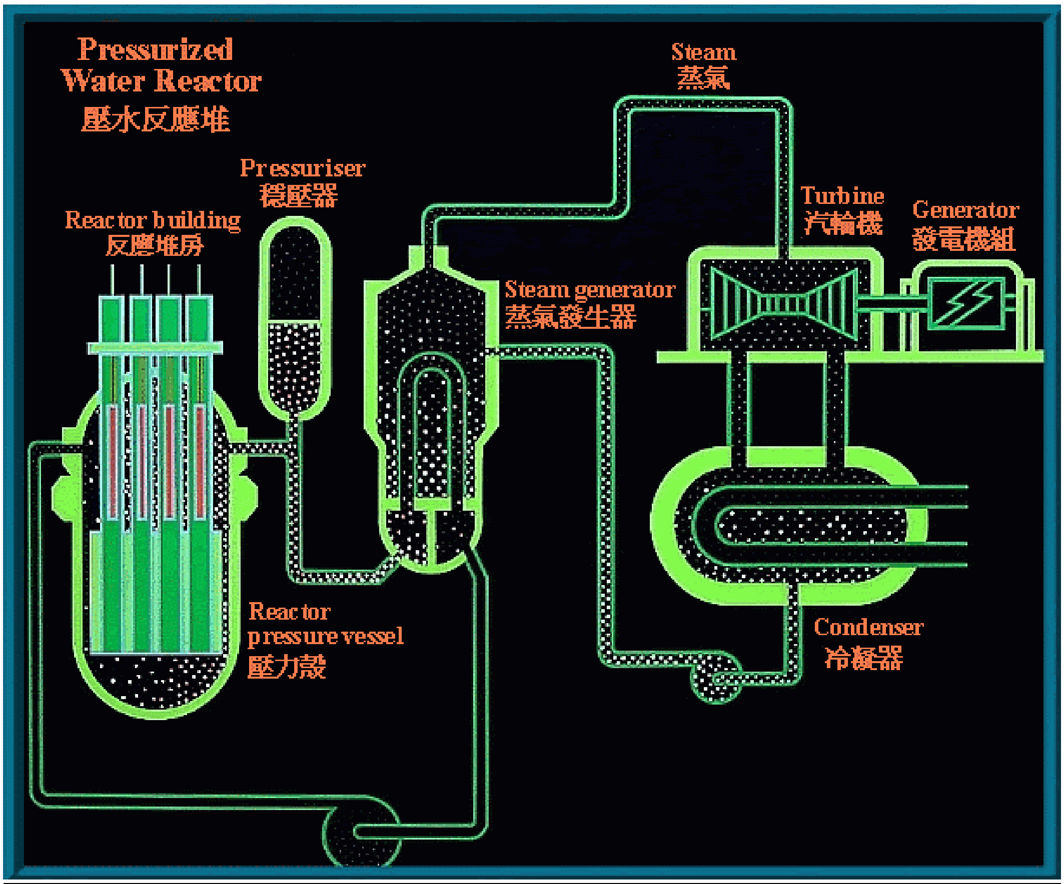
800 kilograms of coal or
570 litres of oil or
450,000 litres of natural gas.

壹顆鈾燃料芯(約直徑 1 厘米及 1.5 厘米長)所提供的能量相當於：

800 千克煤或
570 升石油或
450,000 升天然氣

Display No. 15

What is a nuclear power plant made up of?



Text of the exhibit

A chain reaction can be controlled by limiting the number of neutrons available for fission by an absorber (e.g. boron). This results in a controlled release of energy - nuclear power generation.

連鎖反應可以通過利用吸收劑（例如硼）控制引發裂變的中子數目，從而調節能量的產生，進行核能發電。

Note to the teacher

In a commercial reactor, there are four essential parts:

1) The core contains the fissionable nuclear fuel assemblies. Each assembly consists of a number of metal tubes in which are tiny cylindrical ceramic pellets containing uranium. The assemblies are held in carefully designed geometric arrays by grid plates;

2) The control system serves to regulate the rate of fission and thereby the rate of heat generation;

3) The primary cooling system carries heat from the fuel assemblies; and
4) Additional cooling systems and protection barriers.

Most of the nuclear reactors are of the water-cooled type. Water enters the vessel in a closed cycle, separate from the environment and flows through the spaces between the fuel assemblies in the reactor core. The fission of the fuel creates heat, which then is transferred by the water in the vessel to convert water in a separate circulating system into steam. The steam is then fed to a turbine which drives a generator to produce electricity.

Increasing or decreasing the rate of fission and this the amount of heat is accomplished by inserting or removing control rod assemblies. A reactor operator can stop the fission process by completely inserting the control rod assemblies in the reactor.

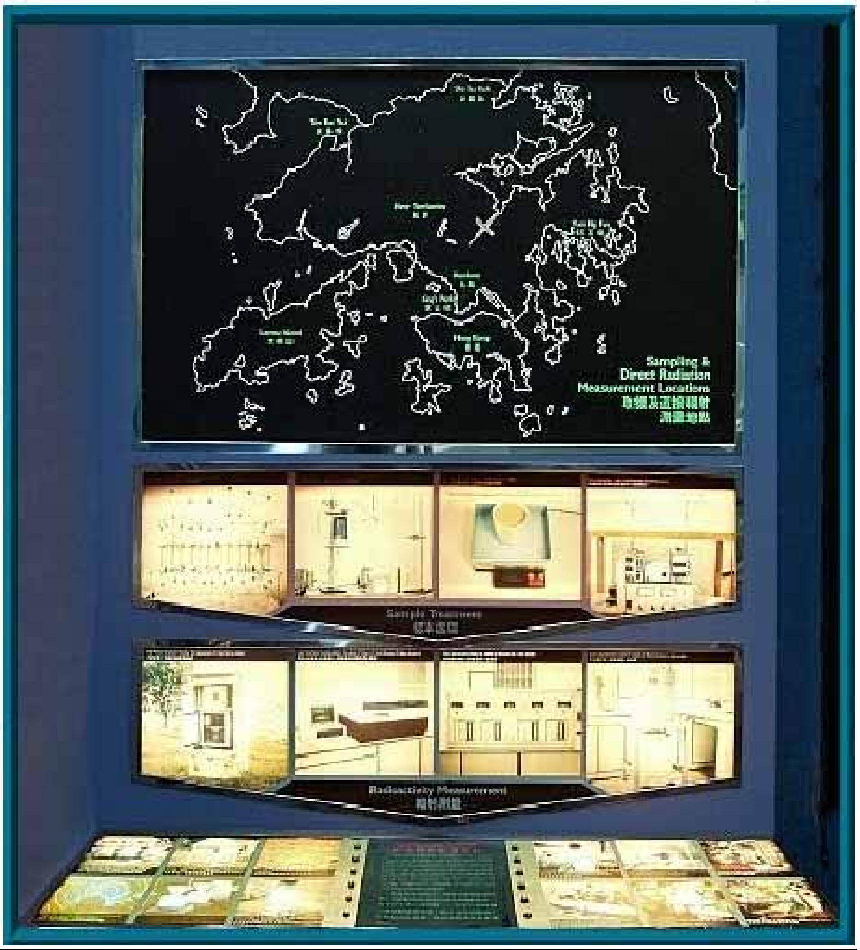
一個商業反應堆有四個基本組成部分：
1）堆芯包含了裂變核燃料組件。每個組件有一些金屬管，貯存了含有鈾的陶瓷小粒子。組件按幾何排列固定在網格板內；
2）控制系統調節裂變率以及產生的熱量；
3）主要冷卻系統將堆芯的熱能傳出；
4）附加的冷卻系統和保護屏障。

大部分核子反應堆屬於水冷型，水注入容器後，便與外界分隔，以封閉循環形式流過堆芯中燃料組件之間的位置。燃料經核裂變產生熱能，容器內的水把熱能傳送，將另一個循環系統的水轉化爲蒸氣，蒸氣再進入汽輪機推動發電機組產生電力。

如要加快或減慢核裂變的速度以調節所產生的熱能，可以插入或拉出組件的控制棒。反應堆的操作人員可以把組件控制棒完全插入反應堆中以停止核裂變程序。

Display No. 16

Environmental Monitoring Programme in Hong Kong



Note to the teacher

This exhibit highlights some of the work carried out by the Hong Kong Observatory in the Environmental Radiation Monitoring Programme (ERMP).

The visitor can manipulate buttons on the lowest panel to obtain information on the ERMP. At the press of a button, say, that corresponding to seawater, the top panel with the map will be lit up to show the locations for seawater collection. In the middle panel, the photographs showing the pre-treatment process and chemical preparation required for the seawater sample prior to radiation measurement are also lit up. Finally, the types of radiation measurement for the seawater samples are indicated by lighting up the appropriate photographs in the lower panel.

There are altogether 12 control buttons on the lowest panel, each of which corresponds to an activity of the ERMP described below:

1. Direct radiation measurement using thermoluminescent dosimeters
   Thermoluminescent dosimeters (TLD) are made of special chemicals that can absorb the energy of gamma rays. The energy absorbed can be released in the form of photons (light) when it is suitably heated. Using a light detectin system to measure the intensity of light emitted, the radiation dose absorbed by the TLD can be estimated to a very high accuracy. The TLD is used in the ERMP to measure direct radiation of both cosmic and terrestrial origins. Radiation dose integrated over an extended period (about 3 months) is measured using TLD.

2. Direct radiation measurement using high pressure ionization chambers
   Gamma radiation can ionize the air contained in a chamber and gives rise to electric current with suitable electronics. This property is made used of in High Pressure Ionization Chambers (HPICs) to detect direct gamma radiation. Unlike TLDs, HPICs are used to measure the instantaneous gamma dose rate and is hence useful for real-time radiation measurement.

3. Collection and measurement of airborne particulates
   Radionuclides of different elements are present in dust particles in air. Dust particles are collected when air is forced to pass through the filter papers.

4. Collection and measurement of wet deposition
   Radionuclides of different elements in air are washed down by rainwater in the form of wet deposition. A 20-litre plastic bottle and a plastic funnel are used to collect wet deposition together with rainwater.

5. Collection and measurement of water vapour, gaseous iodine and carbon dioxide
   Tritium, a radioisotope of hydrogen, is present in the form of water vapour in air. Tritium is formed from several interaction in cosmic rays with gases of the upper atmosphere. Tritium is sampled using a gaseous effluent sampler with a drierite cartridge to absorb water vapour in air.

   Radioiodine is present in air mostly as iodine compound. It is mainly produced by nuclear weapons. A silver impregnated zeolite cartridge is used to collect iodine compounds when the air passes through the cartridge.

   Carbon-14 (C-14), a radioisotope of carbon, is present in the form of carbon dioxide in air. It is produced by cosmic ray reactions in the upper atmosphere resulting in the transmutation of atmospheric nitrogen to C-14. C-14 is sampled using a gaseous effluent sampler with an ascarite cartridge to absorb C-14.

6. Collection and measurement of land soil
A variety of radionuclides are present in land soil. Land soil samples were collected from two layers, up to 30 cm deep.

7. Collection and measurement of seawater
A variety of radionuclides are present in seawater. Seawater up to a depth of 30 metres are collected.

8. Collection and measurement of seabed sediment
Certain radionuclides are preferentially deposited onto seabed sediment. Divers are employed to collect the sediment at a depth of up to metres.

9. Collection and measurement of aquatic foodstuff
Selected species of fishes are obtained from market.

10. Collection and measurement of drinking water
Besides tritium, a number of gamma emitters are present in water.

11. Collection and measurement of poultry and livestock
Beef, pork, duck and chicken are obtained from market.

12. Collection and measurement of vegetables and fruit
Selected species of vegetables and fruit are obtained from market.

這個展覽介紹香港天文台的環境輻射監測計劃（ERMP）所進行的一些工作。

參觀者可以按動最下層展板上的按鈕，閱覽環境輻射監測計劃中相關的資料。例如按下關於海水的按鈕，上層展板的地圖會亮起，展示收集海水樣本的位置，而中間展板則會顯示照片，展示工作人員在測量海水樣本輻射量前處理樣本和進行化學準備的工作。最後，下層展板會展示工作人員量度海水樣本時用的輻射測量方法。

最下層的展板共有 12 顆按鈕，分別對應以下各項環境輻射監測計劃的工作：

1) 利用熱釋光劑量計量度直接輻射

熱釋光劑量計（TLD）含有特殊的化學物質，能夠吸收伽瑪射線的能量。當 TLD 被加熱後，吸收了的能量可以光子（光）形式釋放能量。利用光探測系統，可以非常準確地計算 TLD 所吸收的輻射劑量。ERMP 使用 TLD 來量度來自宇宙和地球的直接輻射。TLD 可以用來量度在一段時期（大約 3 個月）內的總輻射劑量。

2) 利用高壓電離室量度直接輻射

伽馬輻射可以電離容器裡面的空氣，在配上適當的電子後，便可以產生電流。高壓電離室（HPIC）利用這個特性量度直接伽馬輻射。有別於 TLD，HPIC 能量度即時伽瑪劑量率，可應用於實時輻射測量。

3) 收集和測量大氣飄塵

不同元素的放射性核素存在於空氣中的塵埃粒子。空氣被抽入流經過濾紙，把塵埃粒子沉積在過濾紙上收集起來。

4) 收集和測量濕沉積物

空氣中不同元素的放射性核素被雨水沖下形成濕沉降物。一個 20 公升膠瓶及一個膠漏斗把濕沉降物隨同雨水一起收集。

5) 收集和測量水蒸氣、氣態碘和二氧化碳

氚，一個氫的放射性同位素，存在於空氣中的水蒸汽。宇宙射線和大氣層氣體相互影響產生氚。收集氚樣本的取樣器使用含有硫酸鈣的燥石膏濾盒吸收空氣中的水蒸汽。

放射性碘，存在於空氣中大多數的碘化合物，主要由核武器產生。收集氣態碘樣本的取樣器設有銀沸石濾盒，能吸取流過濾盒空氣中的氣態碘。

碳14是碳的一種放射性同位素，存在於空氣中的二氧化碳，大氣層的宇宙射線活動使大氣中的氮轉變成碳14。收集碳14樣本的氣態流出物取樣器設有燒石棉劑濾盒，可以吸收碳14。

6) 收集和測量土壤

各種放射性核素存在於土壤。土壤樣本包括取自兩個不同深度層的土壤，最深達至 30 厘米。

7) 收集和測量海水

各種放射性核素存在於海水中，收集的海水可以深度至 30 米。

8) 收集和測量海床沉積物
某些放射性核素較傾向沉積於海底沉積物，需要僱用潛水員收集深於海底的沉積物。

9) 收集和測量水生食物
從市場收集所選的魚類。

10) 收集和測量食水
除了氚，一些發放γ射線的物質存在於水。

11) 收集和測量家禽及家畜
從市場收集牛肉、豬肉、鴨和雞。

12) 收集和測量蔬菜及水果
從市場收集所選品種的蔬菜及水果。