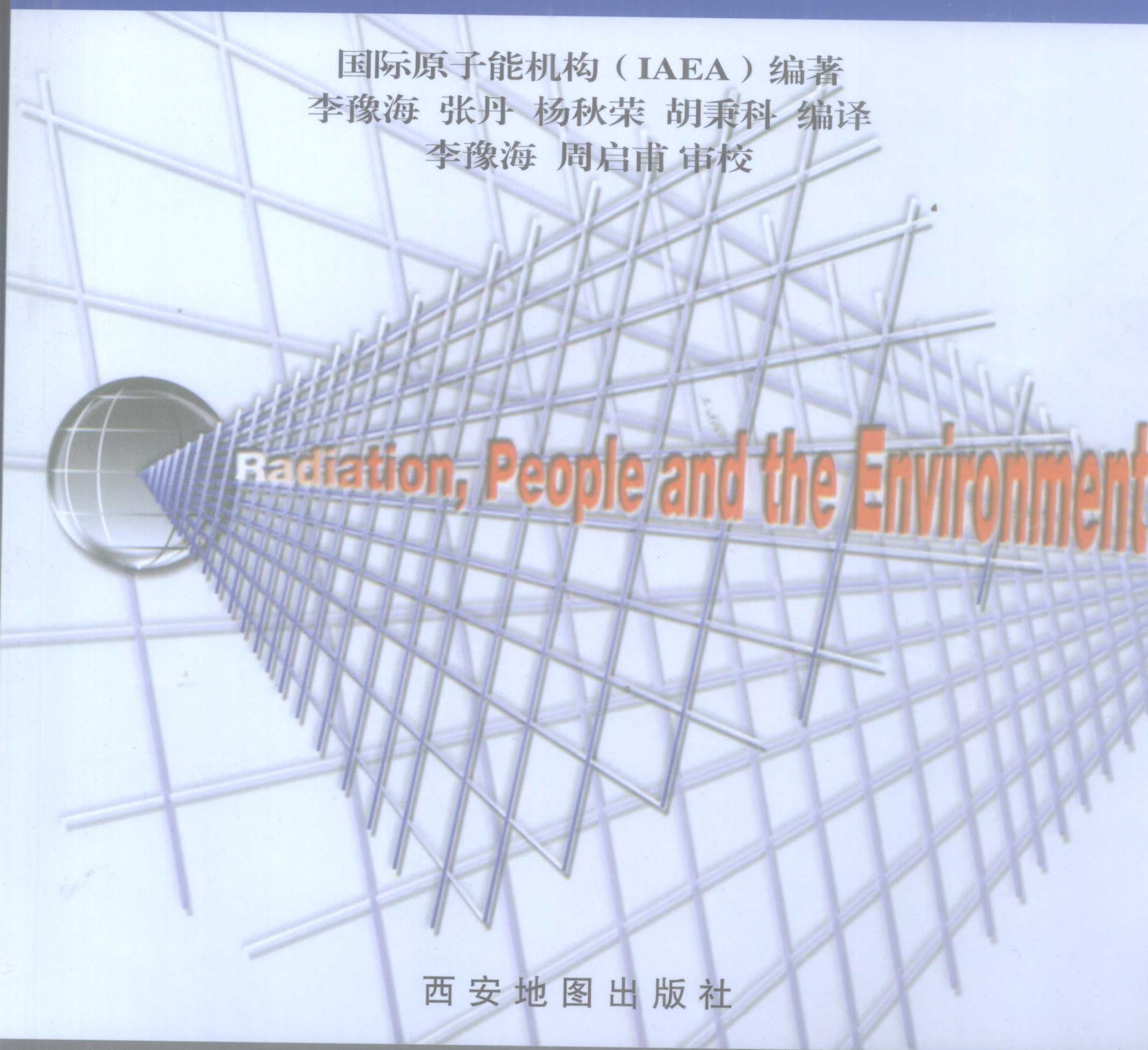
【辐射安全与防护培训教材】

辐射、人与环境（中英文对照）

国际原子能机构（IAEA）编著
李豫海 张丹 杨秋荣 胡秉科 编译
李豫海 周启甫 审校



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目录 Contents

第一章 引言

辐射是不依人的意志为转移的客观事物。在我们赖以生存的环境中，辐射无处不在。太阳发出的由核反应产生的光和热，是人类生存所必需的，天然的放射性物质则广泛地分布于整个环境中，就连我们的身体内，也存在着 ^{14}C，^{40}K 以及 ^{210}Po 之类的放射性核素。地球上的所有生命，都是在存在着此类辐射的背景下不断进化的。

自从一百多年前人类发现 X 射线及放射性以来，人们一直在寻找人工产生辐射及生产放射性物质的方法。X 射线的第一项应用是医学诊断，时间是 1895 年，离 X 射线的发现还不到 6 个月。因此，人们很早以前就认识到了使用辐射会带来好处，但在 19 世纪初，人们同样在不经意地受到过量 X 射线照射的医生身上越来越明显地看到了辐射的某些潜在危险。从那时起，人们一直在开发形形色色的辐射与放射性物质的各种应用。

按照辐射作用于物质时所产生效应的不同，人们将辐射分为电离辐射与非电离辐射两类。**电离辐射**包括宇宙射线、X 射线和来

Chapter 1 Introduction

Radiation is a fact of life. We live in a world in which radiation is naturally present everywhere. Light and heat from nuclear reactions in the Sun are essential to our existence. Radioactive materials occur naturally throughout the environment, and our bodies contain radioactive materials such as carbon-14, potassium-40 and polonium-210 quite naturally. All life on Earth has evolved in the presence of this radiation.

Since the discovery of X rays and radioactivity more than 100 years ago, we have found ways of producing radiation and radioactive materials artificially. The first use of X rays was in medical diagnosis, within six months of their discovery in 1895. So a benefit from the use of radiation was established very early on, but equally some of the potential dangers of radiation became apparent in the doctors and surgeons who unwittingly overexposed themselves to X rays in the early 1900s. Since then, many different applications of radiation and radioactive materials have been developed.

We can classify radiation according to the effects it produces on matter, into ionizing and non-ionizing radiation.

自放射性物质的辐射。**非电离辐射**包括紫外线、热辐射、无线电波和微波。

Ionizing radiation includes cosmic rays, X rays and the radiation from radioactive materials. Non-ionizing radiation includes ultraviolet light, radiant heat, radio waves and microwaves.

本书仅涉及电离辐射，并常常简称为“辐射”。本书是在英国国家放射防护局合作下由国际原子能机构（IAEA）编写的，它概括地介绍了电离辐射、辐射的效应及其应用，以及安全地使用辐射所必需采取的措施。

This book deals with ionizing radiation, a term, which for simplicity, is often shortened to just radiation. It has been prepared by the International Atomic Energy Agency (IAEA) in co-operation with the National Radiological Protection Board (United Kingdom) as a broad overview of the subject of ionizing radiation, its effects and uses, as well as the measures in place to use it safely.

IAEA 作为联合国负责核科学及其和平利用的专门机构，经常在国际范围内提供各种各样的用于促进辐射的安全使用的专门知识和项目。它的法定责任之一是制定可适用于管理使用辐射的各种应用的安全标准。它通过培训班和咨询服务之类的技术合作项目给其成员国提供如何适用这些标准的帮助。它还通过会议和出版物（如本书）促进信息交流。

As the United Nations agency for nuclear science and its peaceful applications, the IAEA offers a broad spectrum of expertise and programmes to foster the safe use of radiation internationally. It has a statutory responsibility for the development of safety standards that are applicable to managing the wide variety of applications that use radiation. It provides assistance to its Member States on the application of those standards through technical co-operation projects such as training courses and advisory services. It also facilitates information exchange through conferences, and publications, such as this one.

利与害

必须分析涉及辐射的任何实践的利益与危害，以便能够有根据地判断此种实践是不是正当的，并使危害最小。电离辐射与放射性物质的发现，导致医学的诊断与治疗有了极大的进步，它们还被广泛地应用于工业、农业和科研中。不过，它们也会伤害人类，因而必须保护人员免受不必要的照射或过量照射。所以，对于我们能够控制的场合，我们必须细心权衡人员会受到辐射照射的那些实践的利与害。

Benefits and risks

The benefits and risks of any practice involving radiation need to be established, so that an informed judgement can be made on their use, and any risks minimized. The discovery of ionizing radiation and radioactive materials has led to dramatic advances in medical diagnosis and treatment, and they are used for a wide range of procedures in industry, agriculture, and research. Nevertheless, they can be harmful to human beings, and people must be protected from unnecessary or excessive exposures. So in circumstances that we can control, we need to make a careful balance between the benefits and the risks of the procedures that expose people to radiation.

公众的忧虑

对电离辐射的最大担忧来源于它可能会使受到照射的人员患上致命的疾病，以及会在后代中出现遗传缺陷。出现此类效应的可能性取决于人员受到的辐射照射的量，不管这种照射是来自天然辐射源还是人工辐射源。随着近几十年来对电离辐射效应的了解越来越多，人们已经开发出了成套的保护人类免受各种辐射源照射的辐射防护办法。尽管如此，公众的忧虑依然存在。

Public anxiety

The greatest concern about ionizing radiation stems from its potential to cause malignant diseases in people exposed to it and inherited defects in later generations. The likelihood of such effects depends on the amount of radiation that a person receives, whether from a natural or an artificial source. As the effects of ionizing radiation have become better understood during recent decades, a system of radiological protection has been developed to protect people from exposure to sources of radiation. But

public anxiety remains.

辐射只是令人生畏的疾病癌症的许多种诱因之一。由于辐射是看不见摸不着的，因而使得这一肉眼无法察觉的危害变得更加令人恐惧。每当人们想起核电站和其他设施发生过的事故、在现今的某些事例中仍在发生的效应，以及往往把任何形式的辐射与包括核武器在内的“核”关联起来的倾向，使得他们更加忧心忡忡。

Radiation is one cause, among many, of the “dread disease” cancer. Our senses cannot detect radiation, making this invisible risk seem even more insidious. Our collective anxiety is strengthened by memories and, in some cases, ongoing effects of accidents at nuclear power plants and other facilities, and by the common tendency to associate any form of radiation with all things “nuclear”, including nuclear weapons.

使人们对辐射的担忧普遍较大的另一个原因，可能与缺乏可靠的、容易取得的信息和由此产生的误解有关。本书的目的就是向非专业人士提供必要的知识。在随后的几章中，我们将介绍各种类型的电离辐射的来源及其效应，并介绍辐射防护的原则与规定准则。

Another contributory reason for general heightened sense of concern about radiation may be the lack of reliable and accessible information and the misunderstandings that arise. The aim of this book is to help by providing information for those who are not experts. In the following chapters, we describe the sources and effects of ionizing radiation of all types and explain the principles and practices of radiological protection.

电离辐射的某些应用

医学的诊断与治疗

核电

工业探伤

医疗设备灭菌

食品辐照保鲜

卫星电池；

科学和医学研究

Some uses of ionizing radiation

Medical diagnosis and treatment

Nuclear power

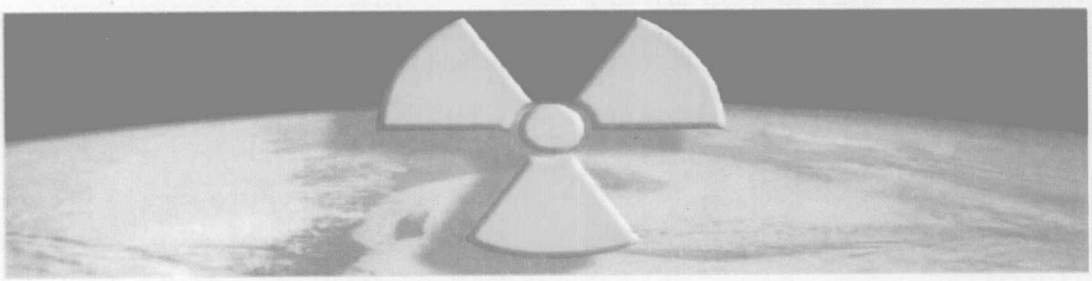
Industrial radiography

sterilization of medical equipment

Food irradiation

Satellite batteries

Scientific and medical research



第二章　原子与辐射

物质的结构

世上万物都是由**原子**构成的。它们就是组成氢、碳、氧、铁和铅之类**元素**的最基本的单元。每个原子包含一个**原子核**以及若干个**电子**。原子核位于中央，体积非常小，带正电荷。电子绕原子核运动，带负电荷，其“轨迹”就是所谓的电子云或电子层，电子云没有固定的**边界**。原子核的直径大约是电子云的万分之一，电子本身则更要小得多。这就是说，原子内部基本上是“空的”，下面我们借助示意图进行描述。

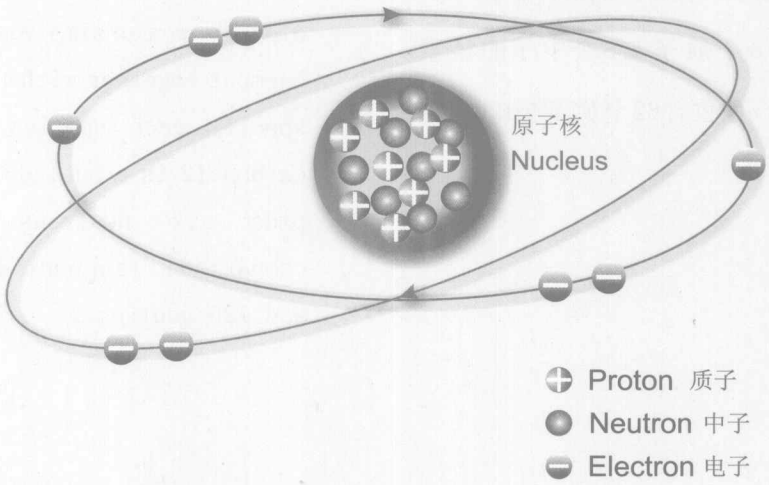
原子中的原子核由**质子**和**中子**组成。质子带正电荷，其电量与电子所带的负电荷相等，中子不带电。这里没有必要介绍质子与中子的更深层次的结构，也没有必要具体介绍它们是如何束缚在原子核内的。每个原子包含的质子与电子的数量相同，因此呈电中性。相同或不同元素的原子可以结合成更大的、不带电的实体，称为**分子**。例如，两个氧原子可以组成一个氧分子，两个氢原子及一个氧原子结合可以组成一个水分子。

Chapter 2 Atoms and radiation

Structure of matter

All matter i n the world about us consists of atoms. These are the basic building blocks of the elements such as hydrogen, carbon, oxygen, iron, and lead. Each atom contains a tiny central positively charged nucleus and a number of electrons. The electrons carry negative electric charge and move around the nucleus in clouds or shells as they are called—with loosely defined boundaries. The nucleus is typically 10 000 times smaller than the electron clouds and the electrons themselves are even smaller. This means that the atom is mainly empty and difficult to depict except in diagrams, which are largely schematic.

The nucleus of the atom contains protons, which carry a positive charge equal to the electron's negative charge, and neutrons, which carry no charge at all. It is not necessary here to consider the more fundamental structure of protons and neutrons, or how in detail they are bound together in the nucleus. Each atom contains equal numbers of protons and electrons and is therefore electrically neutral. Atoms of the same or different elements can, combine to form larger, uncharged entities called molecules. For example, two atoms of oxygen form one molecule of oxygen, and two atoms of hydrogen combine with one atom of oxygen to form one molecule of water.



氧原子的行星模型——中间为包含 8 个质子与 8 个中子的原子核，周围为 8 个轨道电子（The oxygen atom planetary presentation with a nucleus of 8 protons and 8 neutrons within 8 orbital electrons）

原子中的电子的个数——也就是原子核中的质子的个数，这个数被称为**原子序数**，它决定了元素所具有的独特的特性。例如，碳的原子序数是 6，铅则是 82。由于质子与中子的质量基本相同，远远大于电子的质量，因此原子质量的大部分集中在原子核上。质子数与中子数的总和被称为**质量数**。

The number of electrons in the atom and hence the number of protons in the nucleus, called the atomic number gives an element its unique characteristics. The atomic number of carbon is 6, for instance, whereas for lead it is 82. Because protons and neutrons have the same mass, and are much heavier than electrons, most of an atom's mass is concentrated in the nucleus, and the total number of protons plus neutrons is called the mass number.

由于在电中性的原子中，电子数与质子数相等，因此我们能够通过原子所包含的质子数与中子数来标识每一种原子。此外，由于每种元素所包含的质子数是唯一的，因此我们可以简单地使用元素的名称及其质量数来

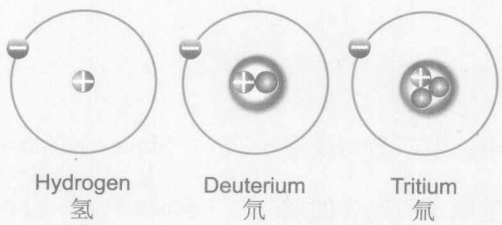
Since the number of electrons equals the number of protons in an electrically neutral atom, we can specify an atomic species by the number of protons and neutrons it contains. Moreover, since the

标识每一种原子，或称作**核素**。譬如，碳-12是一种包含6个质子与6个中子的核素，铅-208则是一种包含82个质子与126个中子的核素。

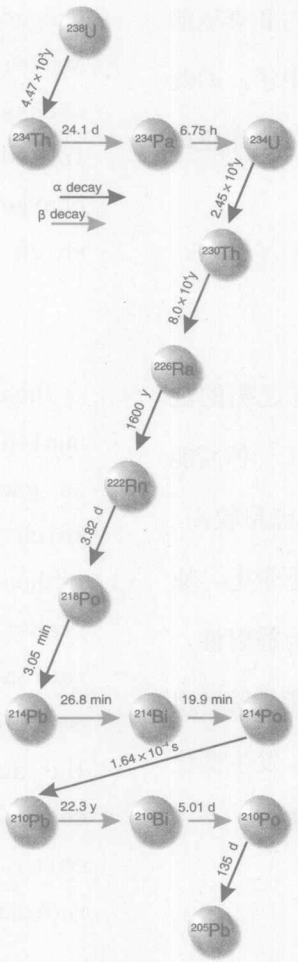
number of protons is unique to each element, we can simply use the name of the element together with the mass number to specify each species or nuclide. So carbon-12 is a nuclide with six protons plus six neutrons. Lead-208, for comparison, is a nuclide with 82 protons and 126 neutrons.

质子数相同但中子数不同的某种元素的各种核素，通称为该元素的**同位素**。例如，氢有三种同位素，氢-1（普通的氢，又称为氕，其原子核中只有一个质子），氢-2 称为氘（一个质子加一个中子），氢-3 称为氚（一个质子加两个中子）。铁有 10 种同位素，从铁-52 到铁-61，它们都有表明它们是铁的 26 个质子，所含中子数则从 26 到 35 不等。

Nuclides of an element that have the same number of protons, but different numbers of neutrons, are called isotopes of that element. Hydrogen, for instance, has three isotopes: hydrogen-1 (common hydrogen with a nucleus of only one proton), hydrogen-2 called deuterium (one proton and one neutron), and hydro gen-3 called tritium (one proton and two neutrons). Iron has ten isotopes from iron-52 to iron-61, all with the 26 protons that characterize the element, but with 26 to 35 neutrons.



氢的同位素（Isotopes of hydrogen）



放射性核素的衰变：铀-238 衰变系中产生的各种辐射和半衰期

(Decay of radionuclides: Different types of radiation and half-lives for uranium-238 series)

放射性与辐射

尽管许多核素是稳定的，但大部分是不稳定的。核素的稳定性主要是由原子核内的质子数与中子数之间的比例决定的。较小的稳定核素，质子数与中子数基本相等；较大的稳定核素，中子数要比质子数稍微多一些。如果原子核中的中子过多，它就会把多余的中子转变成质子，从而使它的结构比较稳定。这个过程被称为贝塔（β）衰变，它能发射一个带负电荷的称为**β粒子**的电子。如果原子

Radioactivity and radiation

Although many nuclides are stable, most are not. Stability is determined mainly by the balance between the number of neutrons and protons a nuclide contains. Smaller stable nuclei have about equal numbers: larger stable nuclei have slightly more neutrons than protons. Nuclei with too many neutrons tend to transform themselves to a more stable structure by converting a neutron to a proton: this process, known as beta decay, results in the emission of a negatively

核中的质子过多，它就会以不同与β衰变的另一种方式把多余的质子转变成中子，即此类质子通过发射带正电荷的电子（称作**正电子**）失去正电荷。

charged electron called a beta particle. Nuclei with too many protons convert the excess protons to neutrons in a different form of beta decay: they lose positive charge through the emission of a positron, which is a positively charged electron.

这些转变经常使原子核具有过剩的能量，它们往往以**伽马（γ）射线**（一种高能**光子**）的形式释放出来。γ射线是能量较高、粒子性较强的光子，既无质量又不带电。原子核发生这种自发转变的现象称为**放射性**，以（电离）辐射的形式将过剩的能量发射出来。这种转变的专用术语为**衰变**，发生变化并发射辐射的核素称为**放射性核素**。

These transformations often leave the nucleus with excess energy that it loses as gamma rays——high energy photons, which are discrete parcels of energy without mass or charge. The spontaneous transformation of a nucleus is called radioactivity, and the excess energy emitted is a form of (ionizing) radiation. The act of transformation is termed decay and the nuclide that changes and emits radiation is called a radionuclide.

某些重原子核会通过释放**阿尔法（α）粒子**进行衰变。这种粒子由两个质子和两个中子组成，与氦的原子核相同。α粒子的质量要比β粒子的大得多，带有两个单位的正电荷。

Some heavy nuclei decay by producing an alpha particle consisting of two protons and two neutrons. Identical with a nucleus of helium, the alpha particle is much heavier than the beta particle and carries two units of positive charge.

天然放射性核素

自然界里存在着许多放射性核素。以碳为例，它通常以含有 6 个质子和 6 个中子的碳-12 的形式存在，非常稳定，但它与大气中的宇宙射线发生相互作用后，能生成含有 6 个质子和 8 个中子的放射性核素碳-14。含有多余中子的碳-14，通过将一个中子转变为质子并发射一个 β 粒子进行衰变，转变成含有 7 个质子和 7 个中子的稳定的氮-14。测量含碳物质的这些衰变是碳断代技术的基础。

Natural Radionuclides

Many radionuclides occur in nature. Carbon, for instance, is mostly in the form of carbon-12 with six protons and six neutrons and is completely stable. Interactions with cosmic rays in the atmosphere can produce carbon-14, a radionuclide consisting of six protons and eight neutrons. Carbon-14, with its extra neutrons, decays by changing a neutron to a proton and emitting a beta particle: in this way, the nuclide transforms to stable nitrogen-14, which consists of seven protons and seven

neutrons. Measuring these decays in carbon-bearing materials is the basis of the technique of carbon dating.

另一些天然存在的放射性核素则是在以铀或钍元素为起点的衰变系中生成的。尽管这两个衰变系的终点都是铅的稳定同位素，但它们还会在衰变过程中形成其他一些大家比较熟悉的放射性核素。在第9页图中示出的是起点为铀-238、终点为稳定的核素铅-206的衰变系，中间还生成过放射性核素氡-222，后者在放射防护中有着特殊的意义。

Other naturally occurring radionuclides are formed in sequences or series of decays that originate from the elements uranium and thorium. Each of these series ends with a stable nuclide of lead, but they also pass through radionuclides of other familiar elements. The diagram shows the decay series from uranium-238 ending in the stable nuclide lead-206: it passes through the radionuclide radon-222, which is of special significance in radiological protection.

放射性核素	不稳定的核素
放射性	发射辐射
辐射类型	α，β，γ，中子和X射线
活度	放射性核素的衰变率
半衰期	活度减半所需的时间

Radionuclides	*Unstable nuclides*
Radioactivity	*Emission of radiation*
Radiation types	*Alpha, beta, gamma, neutron, and X ray*
Activity	*Decay rate of radionuclide*
Half-life	*Time to half activity*

辐射的能量

各种类型的辐射，如α粒子、β粒子和γ射线，其能量通常用**电子伏特**做单位，符号为eV。由于这个单位很小，所以经常使用电子伏特的倍数，如百万电子伏特或10^6电子伏特，符号为MeV。例如，钋-214在衰变时发出的α粒子的能量大约为7.7MeV，铀-238衰变系中形成的铅-214发出的β粒子的最大能量为1.0MeV，伴随产生的γ射线的能量最高为0.35MeV。

在过去的几十年里，人工制造出了几百种天然元素的放射性同位素，如锶-90、铯-137和碘-131。有几种新的放射性元素也已经能大量生产，如钷和钚，尽管在铀矿石里也能找到微量的天然钚。

Radiation Energy

The energy of the various types of radiation —— alpha and beta particles and gamma rays —— is usually expressed in the unit of electron volt, symbol eV. Multiples of this unit are often used; such as a million or 10^6 electron volts, symbol MeV. For instance, the energy of alpha particles emitted by polonium-214 is about 7.7 MeV. Beta particles from lead-214, also formed in the uranium-238 decay series, have a maximum energy of 1.0 MeV, and gamma rays produced by it have energies up to 0.35 MeV.

During the past few decades, several hundred radioactive isotopes (radioisotopes) of natural elements have been produced artificially including, for example, strontium-90, caesium-137 and iodine-131. Several new radioactive elements have also been produced in quantity, for instance promethium and plutonium, although the latter does occur naturally in trace amounts in uranium ores.