# 10MeV 高能大功率辐照加速器

# 10MeV High Energy Irradiation Accelerator


中国★北京

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中國原子能科學研究院
China Institute of Atomic Energy

# 中国核工业集团公司

## 中国原子能科学研究院

中国原子能科学研究院创建于 1950 年，是中国核科学技术的发祥地和先导性、基础性、前瞻性的综合研究基地。

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# 中国首台 10MeV 大功率电子加速器辐照示范工程建成

2007 年 12 月 18 日，由中国原子能科学研究院自主设计研制的 10MeV/15KW 电子加速器辐照装置正式通过验收，这是中国目前能量最高、功率最大，即将投入使用的电子加速器辐照装置。

电子加速器是最主要的辐射源，广泛应用于工业农业医疗卫生环保等领域。形成了一个非常重要的产业集辐照加工产业，在核技术应用产业发展中，电子加速器是辐照加工产业的基础和关键，因此，电子加速器制造与生产占有更突出的地位。与传统的钴源辐照装置相比，10MeV 大功率电子辐照加速器产生的射线具有可控、能量高、辐照时间短、无核废物、不危害环境等特点，被誉为“绿色加工”装置，是符合可持续发展要求的理想辐射源，因此，采用高能大功率电子加速器作为辐照装置是辐射加工产业发展的必然趋势。

辐照杀菌是基于电离辐射在物质内经过直接和间接作用引起生物体内 DNA 失活的一种生物效应。高能大功率电子加速器就是利用加速器产生的电子束或电子束打靶产生的 X 射线进行辐照。其原理是电子束流通过加速管时，由加速管前部的耦合器输入的脉冲微波功率，在加速管建立起高频电磁场使电子束在加速管内不断获得能量而聚焦加速，最后加速到 10MeV/15kW 的高能、大功率电子束从加速管出口输出，当传输链上的被照射物品通过高能电子束辐照区时，吸收的剂量达到足够后，被辐照物品中的生物细菌就会被全部杀死，且被辐照的物品中不会残留有放射性。

高能电子辐照加速器装置主要由电子枪、加速管、微波传输系统、调制器系统、机械支撑系统、真空系统、电子束聚焦系统、控制系统、恒温水冷系统、束流扫描系统等组成。经过研发人员的刻苦攻关，解决了大功率、高重复频率长脉冲高压技术和高功率微波稳定传输与监控等关键技术。经测试，其主要性能、指标居中国领先水平。

一台 10MeV/15kW 高能大功率电子辐照加速器，每年开机 5000 小时，就相当于一座装量为 100 万居里钴源辐照装置。每年可辐照产品 3 万余吨，可实现年业务收入 2 千万元。

该示范工程的建成使中国具备了提供高能大功率电子辐照加速器成套设备的自主设计生产能力，显著提升了中国电子辐照加速器的制造技术和产业化水平，而且对优化辐照产业结构，促进食品安全，提高经济效益，实现可持续发展具有重要意义。



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# China's first 10MeV high-power electron accelerators

# Irradiation demonstration project completed

December 18, 2007, by the China Institute of Atomic Energy 10MeV/15KW independently designed and developed formally adopted electron accelerator irradiation facility acceptance, which is currently the highest energy, power the most, that will be put to use electron accelerator irradiation facility.

Electron accelerator is the most important sources are widely used in industrial agriculture, health and environmental protection fields. Form a set of very important industry in radiation processing industry, industrial development in nuclear technology applications, the electron accelerator radiation processing industry is the foundation and key, therefore, manufacturing and production of electron accelerators occupy a more prominent position. With the traditional cobalt irradiation unit compared to the source, 10MeV electron irradiation accelerator produces high-power radiation with a controllable energy high, irradiation time is short, nuclear waste, do not harm the environment and other characteristics, known as "green process" device, is in line with the ideals of sustainable development requirements sources, therefore, use of high-energy high-power electron accelerator as the radiation device is a radiation processing industry development inevitable trend.

Irradiation sterilization is based on ionizing radiation in the material through both direct and indirect effects within a living body caused by inactivation of DNA as a biological effect. High-power electron accelerators is the use of high-energy accelerators produce electron beams or electron beams, X-rays generated targeting irradiation. The principle is that when the electron beam through the accelerating tube by the accelerating tube coupling the front of the pulse input microwave power, high-frequency electromagnetic fields in the accelerating tube set up so that the electron beam accelerating tube continued to gain energy and focus on speed, finally accelerated to 10MeV / 15kW high-energy, high-power electron beam accelerating tube exit from the output, when the transmission chain of the items being irradiated by high energy electron beam irradiation zone, a sufficient dose absorbed after being irradiated materials in the biological bacteria will be all killed, and the items will not be irradiated radioactive residues.

High-energy electron irradiation accelerator device mainly consists of electron gun, accelerating tube, microwave transmission systems, modulators systems, mechanical support systems, vacuum systems, electron beam focusing system, control system, constant temperature water cooling system, composed of beam scanning systems. Through R & D personnel and overcome problems to solve high-power, high-repetition-frequency long-pulse high-voltage technology and the stability of high power microwave transmission and monitoring key technologies. Been tested, its main performance indicators of the level of China's leading home.

A 10MeV/15kW high-energy high-power electronic irradiation accelerator, turn 5,000 hours per year, equivalent to an installed capacity of 1 million curie cobalt source irradiation facility. An annual three thousand tons of irradiated products could be achieved annual revenues 2 million yuan.

The completion of the demonstration project to provide the Chinese with a high-energy high-power electron irradiation accelerator independent complete sets of equipment design and production capabilities, significantly improve China's manufacturing of electronic irradiation accelerator technology and industry level, but also to optimize the irradiation the industrial structure, promote the food security, improving economic efficiency and achieve sustainable development of great significance.



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# 10MeV/15kW 电子辐照加速器简介

## 10MeV/15kW electron irradiation accelerator

## 一、应用领域与技术原理

Application areas and technical principles

10MeV、15kW 电子辐射加速器是电子辐照加速器从主要用于线缆和热缩材料辐照改性，向灭菌保鲜和海关检疫辐照处理等新的应用领域发展过程中出现的新一代电子辐照加速器产品。由于高能高功率电子辐照加速器具有穿透力强、效率高、杀虫灭菌彻底、工艺过程简单、操作方便、低能耗、高效益、高度机械化、自动化、无污染公害、无残留等特点，目前高能大功率电子直线加速器已成为中国外大力推进发展的射线辐照装置，产业化发展十分迅速，具有广阔的市场前景。

10MeV, 15kW electron accelerator is the electron irradiation accelerator radiation from the main cable and heat-shrinkable material used in irradiation modification to the preservation and customs and quarantine irradiation sterilization and other new application areas arise in the development of a new generation of electronic convergence According to accelerator products. As the high-energy electron irradiation of high-power accelerator has the penetrating power, high efficiency, insect sterilization thorough process simple and convenient operation, low power, high efficiency, high degree of mechanization, automation, non-polluting pollution, no residue and other characteristics, At present high-energy high-power electron linear accelerator has been vigorously promoting the development of China's foreign-ray irradiation equipment, industrial development is very rapid, and has broad market prospects.

传统的消毒灭菌处理手段主要采用环氧乙烷熏蒸、喷雾、焚烧、紫外线照射等方法。这些方法不仅不能达到完全消毒灭菌的目的，还有可能造成环境污染和二次污染。其中有些方法不仅处理量小，而且造价昂贵。目前，国际上采用的一种彻底的消毒灭菌方法就是采用射线消毒灭菌。辐照杀菌是基于电离辐射在物质内经过直接和间接作用引起生物体内 DNA 失活的一种生物效应。射线消毒、灭菌可以有两种方法，一种方法是γ射线消毒灭菌法，一种方法是采用加速器产生的电子束或 X 射线消毒灭菌法。虽然γ射线消毒灭菌具有操作简单、射线穿透力强等优点，但由于γ射线源能量较低，射线方向为 360，射线具有环境污染和废源处理问题等缺点。采用高能电子加速器进行消毒灭菌处理。由辐照加速器产生的高能电子作用于微生物细菌或病原体上，当辐照达到一定的剂量时就会将它们杀死，达到消毒灭菌的目的。

The traditional means of disposing of sterilization using ethylene oxide fumigation major, spraying, burning, ultraviolet radiation and other methods. These methods not only fail to achieve complete sterilization purposes, but also may cause environmental pollution and secondary pollution. Some method is not only the capacity of small and expensive. At present, the international community adopted a radical approach is to use radiation sterilization sterilization. Irradiation sterilization is based on ionizing radiation in the material through both direct and indirect effects within a living body caused by inactivation of DNA as a biological effect. Ray disinfection, sterilization, there are two ways, one way is to g-ray sterilization method, a method is used accelerator produced electron beams or X-ray sterilization method. Although the g-ray sterilization is simple, ray penetration, etc., but because low-energy g-ray source, ray direction 360, rays with a source of environmental pollution and waste handling issues



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shortcomings. Use of high-energy electron accelerators for sterilization treatment. Produced by high-energy electron accelerator radiation acting on the micro-bacteria or pathogens, when it reached a certain dose of irradiation would kill them to achieve the purpose of sterilization.

辐照灭菌使用的射线可以是放射性同位素源产生的γ射线、加速器产生的高能电子束或电子束打靶产生的 X 射线。目前，以电子加速器产生的高能电子束灭菌方法正在成为发展趋势。

Ray irradiation sterilization using radioisotope sources can be produced by g-rays, generated by high-energy electron beam accelerators or electron beam produced by shooting X-rays. At present, high-energy electron accelerators produce electron-beam sterilization methods is becoming a trend.

电子辐照加速器的基本工作原理为：电子枪产生的电子通过线性的加速结构构成的加速管时，在传输的过程中，由加速管前部的耦合器输入脉冲微波功率，电微波的高频电磁场使电子束加速结构不断获得微波能量而聚焦加速，最后加速的高能、高功率的电子束从加速器出口输出，进入扫描空间，利用磁场力将成束的电子扫开成一定的宽度，从薄的金属膜构成的输出窗引出，对运动的被照物件进行辐照，从而达到消毒灭菌的目的。而且被辐照后的物品还不会残留任何放射性。

Electron irradiation accelerator basic working principle of: electron gun produced by the acceleration of electrons through the structure consisting of a linear acceleration controls, in the transmission process, from the accelerating tube the front of the coupler input pulse of microwave power, high-frequency microwave power electromagnetic field so that electron beam to accelerate structural change in the availability of microwave energy and focus on acceleration, the final acceleration of high-energy, high-power electron beam from the accelerator exit out into the scan room, using the magnetic field strength will become the electronic scanning beam into a certain width of the opening, from the thin metal film composed of the output window to bring out the movement of the objects have been carried out according to irradiation, so as to achieve the purpose of sterilization. And were irradiated items will not any radioactive residue.

加速器装置主要由电子枪、加速管、微波传输系统、调制器系统、机械支撑系统、真空系统、电子束聚焦系统、控制系统、恒温水冷系统、束流扫描系统等组成，其主体结构二极型电子枪产生的电子束流通过加速管时，由加速管前部的耦合器输入的脉冲微波功率，在加速管建立起高频电磁场使电子束在加速管内不断获得能量而聚焦加速，最后加速到 10MeV，15kW 的高能、高功率电子束从加速管出口输出，再进入扫描盒，利用扫描磁场将电子束流扫开成一定的宽度，从薄的金属膜构成的输出窗引出，当传输链上的被照射物品通过高能电子束辐照区时吸收剂量，当电子束剂量达到足够的剂量后，其被辐照物品中的生物细菌就会被全部杀死。为了确保灭菌的有效性，世界卫生组织制定了统一的标准，只要控制一定的吸收剂量就能彻底杀灭细菌。且电子束或γ射线、X 射线辐照过的物品中不会残留有放射性。因此这种方法不仅成为一次性医疗用品消毒灭菌的重要手段，也用于邮件、邮包的消毒灭菌、食品的辐照保鲜、粮食和其它农副产品的检疫和贮藏、电力半导体器件和聚合物材料的辐照改性、出口海产品辐照加工、新材料（包括纳米材料）的制备等等，具有非常广的应用前景。

Accelerator device mainly consists of electron gun, accelerating tube, microwave transmission systems, modulators system, mechanical support systems, vacuum systems, electron beam focusing system, control



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system, constant temperature water cooling system, beam scanning systems, etc., whose main structure of two polar-type electron gun produced electron beam through the accelerating tube, by the accelerating tube coupling the front of the pulse input microwave power, high-frequency electromagnetic fields in the accelerating tube set up so that the electron beam accelerating tube continued to gain energy and focus on speed, finally accelerated to 10MeV , 15kW high-energy, high-power electron beam accelerating tube exit from the output, re-entering the scan box, using scanning electron beam scanning the magnetic field will be opened into a certain width from the consisting of thin metal films leads to the output window, when the transmission chain items have been irradiated by high energy electron beam irradiation zone absorbed dose, when the electron beam dose to achieve adequate dose, which has been irradiated in the biological materials will be kill all bacteria. In order to ensure the effectiveness of sterilization, the World Health Organization to develop a unified standard, as long as a certain degree of control can be completely absorbed dose to kill bacteria. And the electron beam or g-rays, X-ray irradiated residual radioactive materials will not. Therefore, this approach has not only become disposable medical supplies an important means of disinfection and sterilization, but also for the mail, parcels of disinfection and sterilization, food irradiation preservation, food and other agricultural quarantine and storage, power semiconductor devices and polymer materials irradiation modification, irradiation of export seafood processing, new materials (including nano-materials) in preparation, etc., have very wide application prospects.

加速管采用 10MeV 行波加速管，具有工作稳定、带宽较宽的特点。电子枪采用大发射电流的二极枪。采用聚焦电磁铁有效控制束流的输运，束流感应监督器监测束流的大小。微波系统为加速管提供高功率微波信号，在加速管内建立起轴向加速电场。它主要由激励源、速调管、波导传输元件、水负载、监控保护装置和充气装置组成。脉冲调制器是加速器的功率源，为电子枪和速调管提供脉冲高压，并为其它电器设备提供低压电源。采用线型调制器，开关管采用英国的闸流管，调制器由调制器配电柜供电，由调制器控制柜控制。真空系统由一台分子泵机组、数台钛泵（包含钛泵电源）及连接管道、阀门组成。真空系统是保证加速器正常运行的必要的系统，它为加速器正常工作提供超高真空度，使电子束能够正常的被加速和传输。恒温水冷系统由冷却水循环系统、制冷循环系统和控制系统组成。采用循环水对加速器各个负载进行冷却，同时通过加热和制冷的手段使水温恒定在一设定的温度范围内，以使加速器负载温度也恒定在这一温度范围内。加速器的控制与安全保护系统是由可编程控制器（PLC）和主控计算机组成，可自动实现加速器开机、出束、停出束、停机的逻辑程序控制；可对加速器进行状态监控和参数设定，并具有安全连锁保护功能，发生异常情况时，控制系统可自动切断加速器高压以及水冷、恒温、磁场电源等系统的供电，并显示故障状态。

Traveling wave accelerating tube with 10MeV accelerating tube, with job stability, wide bandwidth characteristics. Electron gun with large emission current of the diode gun. Focusing electromagnet used to effectively control the beam transport, beam sensor monitoring device for monitoring the beam size. Microwave system for the accelerating tube to provide high-power microwave signals, in accelerating the tube to establish the axial electric field to accelerate. It is mainly from the excitation source, klystron, waveguide transmission components, water load, monitor the composition of the protection devices and inflatable devices. Pulse Modulator is the accelerator power source, in order to provide pulsed electron gun and klystron high voltage and other electrical equipment for low-voltage power supply. Using linear modulator, switch thyratron with the United



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Kingdom, modulators, power distribution equipment by the modulator power supply, controlled by the modulator control cabinet. Vacuum system consists of a molecular pump units, the number of sets titanium pump (with titanium pump power) and the connecting pipes, valves formed. Accelerator vacuum system is to ensure the normal operation of the necessary system, it provides ultra-high vacuum accelerator work degree, so that the normal electron beam can be accelerated and transmission. Constant temperature water-cooled system is composed of the cooling water system, cooling circulation system, and control system. Use of recycled water for cooling the load on the accelerator at all at the same time by heating and cooling means so that the water temperature constant at a set temperature range, so that the load temperature accelerator constant in this temperature range. Accelerator control and safety protection system is operated by programmable logic controller (PLC) and the host computer, the accelerator can be automatically boot out the beam, a beam stop, shutdown logic control; may accelerator for condition monitoring and parameter settings, and security-chain protection, when an irregularity occurs, the control system can automatically cut off the accelerator, as well as high-pressure water-cooled, temperature, magnetic fields, power supply systems such as power supply, and display fault condition.

## 二、性能指标

performance indicators

- ✧ 束流初始能量 60KeV
- ✧ 束流初始流强 650mA
- ✧ 加速器入口束斑 ϕ3mm
- ✧ 速调管输入功率（脉冲） 5MW
- ✧ 速调管输入功率（平均） 45KW
- ✧ 微波频率 2856MHz
- ✧ 重复频率 20-650pps 可调
- ✧ 脉冲宽度 15μs
- ✧ 加速器能量 10 MeV
- ✧ 加速器脉冲束流 160~220 mA
- ✧ 加速器平均束流 1.5~2.0 mA
- ✧ 加速器平均功率 15~20 KW
- ✧ 束流能散 ±5%
- ✧ 扫描宽度 700 mm（钛窗下 500mm 处）
- ✧ 束斑 ϕ50 mm（钛窗下 500mm 处）
- ✧ 传输链速度 5-20 m 可调

beam initial energy 60KeV

The initial flow of strong beam 650mA

accelerator entrance beam spot ϕ3mm

klystron input power (pulse) 5MW

klystron input power (average) 45KW

Microwave Frequency 2856MHz

adjustable repetition rate 20-650pps



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pulse width 15ms

energy of 10 MeV accelerator

accelerator beam pulse 160 ~ 220 mA

The average beam accelerator 1.5 ~ 2.0 mA

15 ~ 20 KW average power accelerator

beam energy spread ± 5%

Scan Width 700 mm (Ti-500mm at the window)

beam spot f50 mm (Ti-500mm at the window)

delivery chain speed of 5-20 m Adjustable


2007 年 12 月 18 日“大功率电子辐照加速器示范工程”建成剪彩

December 18, 2007, "High-power electron irradiation accelerator Demonstration Project" into the ribbon-cutting



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大功率电子辐照加速器示范工程-控制室

High-power electron irradiation accelerator Demonstration Project - Control Room

大功率电子辐照加速器示范工程-设备机房

High-power electron irradiation accelerator demonstration project - equipment room



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大功率电子辐照加速器

High-power electron irradiation accelerator



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束下输送系统 delivery system under the Beam

辐照产品库房 Irradiation warehouses

10MeV/15kW high-energy high-power radiation accelerator device

Quote

| No. | Name of goods | model | Amount | price of goods (RMB) | Delivery |
|---|---|---|---|---|---|
| 1 | 10MeV/15kW high-energy high-power radiation accelerator device | FZ-10 | 1unit | RMB: 13 million yuan | After the signing of the contract within 20 months of completion of installation and commissioning |

| | | |
|---|---|---|
| 1 | Name of goods | 10MeV/15kW high-energy high-power radiation accelerator device |
| 2 | Origin | Beijing • China |
| 3 | unit | 1 unit |
| 4 | Accelerator Device | (RMB) |
| 10 | Technical support service fee | 150,000 yuan / 1 year (in China) (RMB) |
| 11 | Setup、Testing, | 150,000 yuan (in China) (RMB) |
| 12 | Training | 50,000 yuan / 1 year (in China) (RMB) |
| 13 | Transport (to destination) | 50,000 yuan (in China) (RMB) |
| 14 | Transportation insurance | 40,000 yuan (in China) (RMB) |



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## 其他费用估算、预算 Other estimate cost and budget

| | | |
|---|---|---|
| 1 | Environmental Assessment | 500,000 yuan (RMB) |
| 2 | Plant design fees | 800,000 yuan (RMB) |
| 3 | Plant construction costs | 550,000 thousand yuan (RMB) |
| 5 | Device under the Beam Transmission | 1100,000 yuan (RMB) |

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## 六、辐照加速器装置方案 Irradiation Accelerator Device Program

### 1.基本原理 Basic principles

由辐照加速器产生的高能电子（或 X 光子），作用于微生物细菌或病原体，达到一定的剂量（如 25KGy）就全部将它们杀死，达到消毒灭菌的目的。本项目涉及的高能电子辐照加速器，是采用微波功率射频加速的电子直线型加速器。其基本工作原理为：电子枪产生的电子通过线性的加速结构构成的加速管时，在传输的过程中，由加速管前部的耦合器输入脉冲微波功率，电微波的高频电磁场使电子束加速结构不断获得微波能量而聚焦加速，最后加速的高能、高功率的电子束从加速器出口输出，进入扫描或偏转/扫描空间，利用磁场力将成束的电子扫开成一定的宽度，从薄的金属膜构成的输出窗引出，对运动的被照物件进行辐照。高能电子束还可以照射在重金属靶上，产生韧致辐射，利用其转换成的 X 光辐照被辐照物件，穿透能力则大大增加。

Radiation produced by high energy electron accelerator (or X photons), acting on the micro-bacteria or pathogens, up to a certain dose (eg 25KGy) in respect of all to kill them to achieve the purpose of sterilization. The project involves high-energy electron irradiation accelerator is the use of radio frequency microwave power electron linear accelerator accelerating. The basic working principle of: electron gun produced by the acceleration of electrons through the structure consisting of a linear acceleration controls, in the transmission process, from the accelerating tube the front of the coupler input pulse of microwave power, microwave power of high frequency electromagnetic field so that electron beam accelerate the structural change in the availability of microwave energy and focus on acceleration, the final acceleration of high-energy, high-power electron beam accelerator exit from the output, enter the scan or deflection / scanning space, the use of magnetic force will become the electronic scanning beam into a certain width of the opening, from the thin metal film composed of the output window to bring out the movement of the objects was carried out according to irradiation. High-energy electron beam irradiation can also be on the heavy metal target to produce bremsstrahlung, using its conversion into X-ray irradiation were irradiated objects, penetration is greatly increased.

### 3. 主要技术指标 Main Technical Specifications

**表 8　　FZ—10/15—1000 型加速器主要技术指标**

Table 8 FZ-10/15-1000 type accelerator key technical indicators

| | |
|---|---|
| Accelerator Type | Traveling-wave electron linear accelerator |
| Electron beam energy | 10MeV |
| Frequency | S-band 2856MHz （±2MHz） |
| Output power | 15kW |
| Output-ray type | Electron beam |
| Continuous work | Allow 8 hours continuous operation |
| Scan Width (mm) | 1000mm x 25mm |
| Temperature | 5-35° C |



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## （二）其他系统 Other systems

### 1. 传输系统 Transmission System

辐照传送带出入口放在一起，便于工人操作。通道宽 2.5m，传送带宽 1.2m，两边为 0.65m 走道，传送带高 0.6m，传送带沿墙周边盘环行走，环形传送带中间有屏蔽墙，防止二次辐射，传送带为滚轮结构，自动控制。整个传送系统分为 5 段，即：进料段、辐照段、出料段、翻转段和循环段。

Radiation belt entrance together to facilitate workers to operate. Corridor width 2.5m, transmission bandwidth of 1.2m, on both sides of the aisle for the 0.65m, belt high-0.6m, conveyors run along the wall around the plate ring, ring the middle belt shield wall, to prevent the secondary radiation belts for the wheel structure, and automatic control. The entire transmission system is divided into five paragraphs, namely: the feed section, irradiating section, discharging section, flip section and recycling segment.

### 2. 厂房要求 Plant requirements

厂房要有进料装卸和暂存库、辐照厅、接待室，二层有加速器防护厅、实验室、剂量室、控制室，调制器室，水冷间及办公用房。

Plant must feed handling and temporary library, irradiation hall, reception room, second floor there are protective accelerator hall, laboratories, dose-rooms, control rooms, modulators room, water-cooled rooms and office space

### 3. 动力供应 Power supply

辐照加速器总耗电量为 335kW，其各部件需用电约为：

- 调制器： 120kW
- 水冷机组： 170kW
- 控制： 5kW
- 传送系统： 30kW
- 磁场： 5kW
- 照明及墙上电源： 5kW

为此，需 350kVA 变压器一台提供 380V 供电，电力负荷等级为二级，遵照国家有关工业规范及标准进行设计。

Irradiation Accelerator total electricity consumption of 335kW, its various components required to power approximately:

modulator: 120kW

Water-cooled units: 170kW

Control: 5kW

Transmission System: 30kW

magnetic field power: 5kW

lighting and other Power: 5kW

To this end, take a 350kVA transformer to provide 380V power supply, power load rating of 2, in accordance with national norms and standards relating to industrial design.



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**医疗用品辐射消毒灭菌的产业发展**

医疗用品消毒方法通常有：高温高压法、化学法和辐射法。

高温高压加热消毒法虽早已成为成熟的常规消毒方法，但因能源消耗大、消毒不彻底及对某些物质的破坏性，其消毒量已逐年下降。

40 年代发展起来的化学消毒法，到 70 年代遇到了辐照消毒法的竞争，化学消毒法的缺点日益暴露。如化学消毒用的环氧乙烷（ETO）消毒剂，是一种致癌物质，医疗用品用其消毒后必须存放一定时间，使其残留量低于 2ppm 才能使用，而存放期内又可能出现再次污染；ETO 消毒要求条件较严格，如温度、湿度、浓度等，条件稍有变化，就会影响消毒效果；用 ETO 气体消毒，待消毒物品需用透气性好的包装材料，这必然增加包装成本；ETO 气体的排放会对周围环境和人员造成污染和伤害。这些都促使已采用 ETO 消毒的厂家逐渐向辐射消毒转移。

辐射灭菌法有如下优点：

1.节约能源。辐射法的能源消耗与加热法和化学法之比约为 1：40~1：200。

2.消毒灭菌彻底。辐射剂量为 $10^5$~$10^6$ 拉德时，可使活的细菌、霉菌、真菌的数量减低到百万分之一；剂量达到 $10^6$~$4\times10^6$ 拉德时，可使病毒数量减少到百万分之一。

3.可常温灭菌。特别适用于热敏材料制成的医疗用品及生物制品、敷料等。

4.灭菌过程操作简便快捷。γ 射线穿透力强，产品可置于成品包装箱密封灭菌，可自动控制、连续作用。如用加速器灭菌，则由于其能量高而使灭菌过程更加迅速。

5.无化学残留和污染，也不会感生放射性。

6.密封包装产品辐射灭菌后可长期保存，不会再污染，更有利于战备、野外和流行病区使用。

辐射灭菌除上述技术、经济上的优点外，还同时带来重大的社会效益。如日本、南斯拉夫等国过去都曾是肝炎患者多的国家，自从采用辐照灭菌的一次性使用的注射器后，逐渐消除了肝炎交叉感染，使发病率大大下降。



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## Radiation sterilization of medical supplies for industrial development

Medical supplies sterilization method usually include: high temperature and pressure, chemical and radiation method. High-temperature high-pressure heat sterilization method has long since become a mature conventional disinfection methods, but the energy consumption, disinfection is not thorough and destructive to certain substances, the disinfection capacity has been declining.

40 years developed chemical disinfection method, to the age of 70 has encountered a irradiation sterilization law, competition, chemical disinfection of the shortcomings of the increasing exposure. Such as chemical disinfection with ethylene oxide (ETO) disinfectant, is a cancer-causing substances, medical supplies after disinfection should be stored with its certain period of time to less than 2ppm residues can be used, but they may occur during storage re-contamination; ETO sterilization requirements more stringent conditions such as temperature, humidity, concentration, conditions a slight change will affect the disinfection effect; by ETO gas sterilization, to be sterile packaging materials need to use a good air permeability, which will increase packing costs; ETO gas emissions will pollute the surrounding environment and personnel and injuries. These are ETO sterile prompted manufacturers have adopted a gradual shift to the radiation sterilization.

Radiation sterilization has the following advantages:

1. To save energy. Radiation of energy consumption and heating method and the chemical ratio of about 1:40 ~ 1:200.

2. Disinfection and sterilization completely. Radiation dose of 105 to 106 rad, the can of live bacteria, mold, fungi number reduced to one in a million; a dose of 106 ~ 4 × 106 rad, the viral load can be reduced to one in a million.

3. May be at room temperature sterilization. Especially suitable for heat-sensitive material and biological products, medical supplies, dressings and so on.

4. Sterilization process operation simple and quick. γ-ray penetration, the product can be placed in sealed sterile packaging finished products can be automatic, continuous effects. As with the accelerator sterilized, then through high energy due to its sterilization process more quickly.

5. No chemical residue and contamination, nor induced radioactivity.

Six. Sealing packaging products can be stored for a long post-radiation sterilization, will not be pollution, more conducive to combat readiness, the use of wild and endemic areas.



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Radiation Sterilization In addition to these technical and economic advantages, but also bring significant social benefits at the same time. Such as Japan, Yugoslavia and other countries in the past have all been patients with hepatitis and more countries, since the use of radiation sterilization of the disposable syringe, the gradual elimination of cross-infection of hepatitis, so that the incidence declined significantly.

## 术语

i.

**辐射加工 radiation processing**

电离辐射作用于物质，使其品质或性能得以改善的一种工艺过程。

ii.

**辐射装置 radiation facility**

由辐射室、电子加速器装置、束下装置、控制系统、安全设施等组成的辐射加工工艺装置。

iii.

**辐射加工用电子加速器装置 electron accelerator facility for radiation processing**

**电子加速器装置 electron accelerator facility**

产生、加速、引出电子束流用于辐射加工的装置。

iv.

**束下装置 facility under beam**

泛指束流引出窗下（外），用于输运物料进行辐射加工的装置。

v.

**参考面与参考点 reference plane and reference point**

辐射场中，选定的垂直于束流轴线的平面称为参考面，束流中心轴与参考面相交的点称为参考点。

注 1：通常取参考面在束流引出窗外并与引出窗相距不大于 200mm。

注 2：如图 1 所示，在直角坐标中，与束流中心轴—Z 轴相垂直的 X、Y 两坐标组成的平面为参考面，Z 轴与参考面相交的点 O 为参考点。



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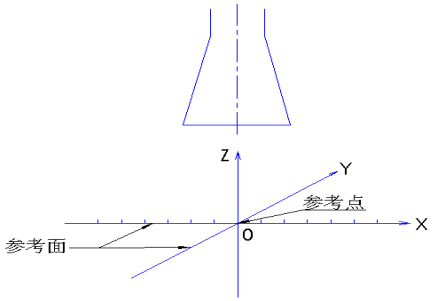


图 1 参考面与参考点示意图

vi.

**电子束流能量 electron beam energy**
**束流能量 electron beam energy**
电子束流（以下简称“束流”）在参考面处的最可几能量。
注：束流能量的符号为$E_p$，单位为MeV。

vii.

**束流能量不稳定度 electron beam energy instability**
给定时间内，由于加速器参数的未受控自然变化导致束流能量的变化率。
注：能量不稳定度以百分比表示。

viii.

**束流强度 electron beam intensity**
通过参考面的束流的时间平均值，对于脉冲加速器是指平均束流强度。
注：束流强度的符号为$I_e$，单位为mA。

ix.

**连续束流 continuous electron beam**
时间上持续存在的束流，束流幅度不随时间变化。

x.

**脉冲束流 pulse electron beam**
周期性出现的重复性束流，但束流存在的持续时间远小于无束流存在的持续时间。

xi.

**束流脉冲重复率 electron beam pulse rate**
以单位时间脉冲数表征的脉冲束流周期性参量。
注：束流脉冲重复率的符号为N，单位为pps。

xii.

**束流强度不稳定度 beam intensity instability**
给定时间内，由于加速器参数的未受控自然变化导致束流强度的变化率。
注：束流强度不稳定度以百分比表示。

xiii.

**束流焦斑直径 electron beam focal spot**


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束斑直径 electron beam focal spot

未经扫描的束流，通过束流引出窗在参考面上形成的束流密度分布，称为束流焦斑（简称束斑）。以束流密度为束斑中心处50%的等密度圆周的直径为束斑直径。

注：束流焦斑直径符号为$\Phi_e$，单位为mm。

xiv.

束流扫描频率 electron beam scanning frequency

在周期性（电）磁场作用下，束流沿引出窗宽度方向周期性扫描，单位时间内束流扫描的周期数。

注：束流扫描频率的符号为$f_{sw}$，单位为Hz（或$S^{-1}$）。

xv.

束流扫描宽度 electron beam scanning width

束流经扫描后在参考面上形成的垂直于产品运动方向的有用束流宽度。

注：束流扫描宽度的符号为$W_e$，单位为mm。

xvi.

束流扫描不均匀度 electron beam scanning uniformity

在参考面上，束流扫描宽度内，束流密度分布的不均匀程度。以最高束流密度与最低束流密度之比表示。

xvii.

束流功率 electron beam power

单位时间束流所做的功。其数值为束流能量乘以束流强度除以电子电荷。

注：束流功率的符号为$P_e$，单位为kW。

xviii.

束流射程 beam range

测试模块表面处于参考面，沿辐射束流轴线的深度剂量曲线上，下降最陡处的切线外推线与深度吸收剂量曲线末端的外推线相交处所对应的深度。

注：束流射程的符号为$R_p$，单位为$g/cm^2$。

xix.

电离辐射 ionizing radiation

由能够产生电离的带电粒子和（或）不带电粒子组成的辐射。电离辐射也称射线。

xx.

辐射场 radiation field

电离辐射在所考虑的介质中的空间-时间分布。

xxi.

辐射区 radiation area

人员可能受到剂量率超过1 mSv/h辐射的区域。

xxii.

控制区 controlled area

要求或可能要求采取专门措施方可允许放射性专职人员驻留的区域。

xxiii.



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**监督区 supervised area**

不需要采取专门措施，但要定时检查驻留人员职业受辐射状况的区域。

xxiv.

**非控制区 noncontrolled area**

不需采取专门措施，允许公众人员驻留或经过的区域。

xxv.

**剂量测量系统 dosimetry system**

由剂量计、相关的分析仪器及剂量响应校准曲线（或剂量响应函数）组成的用于确定吸收剂量的系统。

xxvi.

**加工能力 processing throughput**

辐射装置在单位时间内能够处理的物料量和被辐射的物料吸收剂量乘积的最大值。

xxvii.

**束下装置传输速度 conveyor speed of facility under beam**

束下装置输运的辐射物料，在经过束流引出窗处的传输速度。

注：束下装置传输速度的符号为$V_L$，单位为m/min。

xxviii.

**吸收剂量 absorbed dose**

电离辐射授予单位质量物质的平均能量。

注：吸收剂量的符号为D，单位为J/kg,专用名称为戈瑞（Gray），符号为Gy。

xxix.

**当量剂量 equivalent dose**

人体某一组织或器官T所接受的吸收剂量，当组织或器官接受不同辐射质辐射时，需对辐射做辐射质加权处理，但在辐射加工的电子束能量限制（≤10MeV）条件下，辐射质权重因子为1。当量剂量是辐射防护剂量学中的基本量。

注：当量剂量的符号为Ht,单位为J/kg,专用名称为希沃特（sievert）,符号为Sv,1Sv=1J/kg。

xxx.

**剂量率 dose rate**

物品或人体特定组织器官或人体所有组织在单位时间内所接受的吸收剂量或当量剂量。

注1：剂量率的符号为$\dot{D}$或者$\dot{H}_T$，单位为Gy/s或Sv/s。

注2：辐射加工剂量率单位通常用kGy/min，防护剂量率单位通常用mSv/h。



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