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辐射加工在我国经济增长中的产业化进程

INDUSTRIALIZATION DRIVE OF RADIATION PROCESSING FOR ECONOMIC GROWTH IN CHINA

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摘　　要

就我国辐射加工从研究开发成果向常规工业应用转移进行了论述。在简要地回顾了我国辐射加工产业化的历史背景之后，着重指出了各有关部门在产业化进程中所起的不同作用。其中政府的作用最为关键。根据近年来全国各地区所建立的辐射装置（钴-60辐照器与电子束加速器）的数量增长情况，以及辐射加工在主要领域中的应用，现在可以说我国已初步形成了一种崭新的辐射加工产业，旨在满足经济繁荣日益增长的需求。

Industrialization Drive of Radiation Processing for Economic Growth in China

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ABSTRACT

The transfer of research and development achievements of radiation processing to routine industrial applications in China is reviewed. While making a brief survey of historical background, the paper indicates the different roles that various domestic organizations played in the industrialization drive of radiation processing. Among them the Government's role is the most important. In accordance with recent growth of the number of industrial radiation facilities (e. g. cobalt-60 irradiators and electron beam accelerators) and current application of radiation processing in main fields in different parts of the country, it can be said that a new radiation processing industry is shaping up in its developing stage to satisfy the growing requirements for economic booming in China.

INTRODUCTION

The term " radiation processing" is a general expression, that refers to a category of technology of utilizing various kinds of high energy ionizing radiation (e. g. gamma-ray and electron beam) to derive physical, chemical and biological effects on absorbed materials through their interactions. Being similar to other conventional industrial technologies (e. g. heat treatment, mechanical working and chemical processing), radiation processing can be considered as a modern technology for changing materials to achieve the desired characteristics. During the past four decades extensive researches and developments have resulted in widespread applications of radiation processing on a industrial scale with significant technical and economic benefits in a number of developed countries all over the world.

It is obvious that radiation processing in various industries is, in many respects, unique and cannot be replaced by other conventional technologies because of its following inherent features:

——Low-temperature capability, derived from radiation-induced chemical reactions at any temperature;

——Easy control of reaction rate and product quality, simply done by controlling dose rate of penetrating radiation;

——Free of any catalyst and its residue in the system because of radiation initiation;

——The capability to initiate solid-phase reaction;

——The capabitity of high-speed treatment.

Economic competitiveness of radiation processing depends on the successful transfer of the technologies from research laboratories into the routine use and the industrial utilization at a sufficient large scale used as on-line process or on a service basis in addition to technological merits. In other words, the technological industrialization of radiation processing is a only gateway to creating business opportunities of making a profit.

However, the industrialization drive of radiation processing is a complex technical and economic activity involving the concerted endeavours on a variety of aspects such as research, engineering, manufacture, business, trade, commerce, marketing and finance to turn the scientific achievements into commercialized products and services in the competitive market.

At present, the role of radiation processing in the modernization and optimization of important traditional industrial sectors and in the emergence of new high-tech industries is gaining greater recognition in developing countries due to its advantages on the following aspects:

——Promotion of traditional industries' transformation and upgrade due to the introduction of modern production-line;

——Formation of new high-tech industries with the local characteristics to boom the economy;

——Manufacture of new, high value-added products or quality improved products;

——A saving on energy consumption and raw materials;

——Reduction of imported products and services by partial self-reliance;

——Benefit to environment protection due to the elimination of harmful chemical residues in radiation treated products and the decrease of pollutant emmission in technological process.

In China, the research and development of radiation utilization in industries, medicine and agriculture had been being an integral part of national nuclear programme until the 1980's when there was a new strategic policy of reform and opening to the out world to be enacted and since then economic growth has been accompanied by an increasing demand for access to the benefits of modern technologies, including radiation processing.

Therefore, the technological industrialization drive of radiation processing was put on the agenda of national development for science and technology[1].

1 INDUSTRIALIZATION DRIVE

1.1 Brief survey of historical background

In the late 1950's, the early utilization of radiation chemistry was dealt with the scientific researches on radiation stability of extractants, ion-exchange resins and flocculents for nuclear industry. After that, the researches and developments turned to modifying polymers and other related products. The research achievements on radiation cross-linked heat shrinkable materials and wires by Chinese experts were successfully used in China's first satellite in the 1960's. Since then, the polyacrylamide produced in batches by radiation has become the first pilot-test product which was used in oil industry. Meanwhile an electron beam accelerator Dynamitron with power of 120 kW was introduced from the United States and installed in China's northeastern Jilin province for demostration. During that time

Chinese nuclear experts in the scientific institutions and universities in different parts of the country became a main force to promote various applications of radiation technology.

Up to the 1980′s, with the strategic emphasis of Chinese nuclear programme being shifted to the service for national economic construction and improvement of people′s life, the industrialization drive of radiation processing was faced with both golden opportunities and great challenges. Since then, an increasing number of industrial radiation facilities, including cobalt-60 irradiators and electron-beam accelerators, installed in different parts of the country have become an impetus to the industrialization drive. In the meanwhile a variety of radiation products have been put into the market to fulfill the domestic demands. Therefore, it can be said here that a new radiation processing industry is shaping up in its developing stage in China[2].

It has been proved in practice that following prerequistes were the essential guarantee of the success for the industrialization drive of radiation processing:

——Well-established technology in developed countries;

——Relatively a complete domestic system of nuclear industry;

——A moderate infrastructure, including enough resources in terms of technology and personnel;

——Conforming to the current national principle of science and technology " the economic construction must rely on the promotion of science and technology, the work of science and technoloty must face the economic construction";

——Exchange and cooperation with other foreign countries and international organizations such as International Atomic Energy Agency (IAEA), Food and Agricultural Organization (FAO), World Health Organization (WHO) and United Nations Development Programme (UNDP).

——Poor strength of the opposite demostic force against the peaceful use of nuclear energy.

1.2 Transfer of technology and project identification

Transfer of technology is never a single and discrete process. The long-term practice of the drive in China has proven that the technological industrialization is acturally a system engineering, involved in a number of orderly links in a whole chain, including basic and applied researches, technology transfer, pilot test, product innovation, production capability, business management, market survey and exploitation etc. (Fig. 1). Every link is in relation to each other besides the cascades.

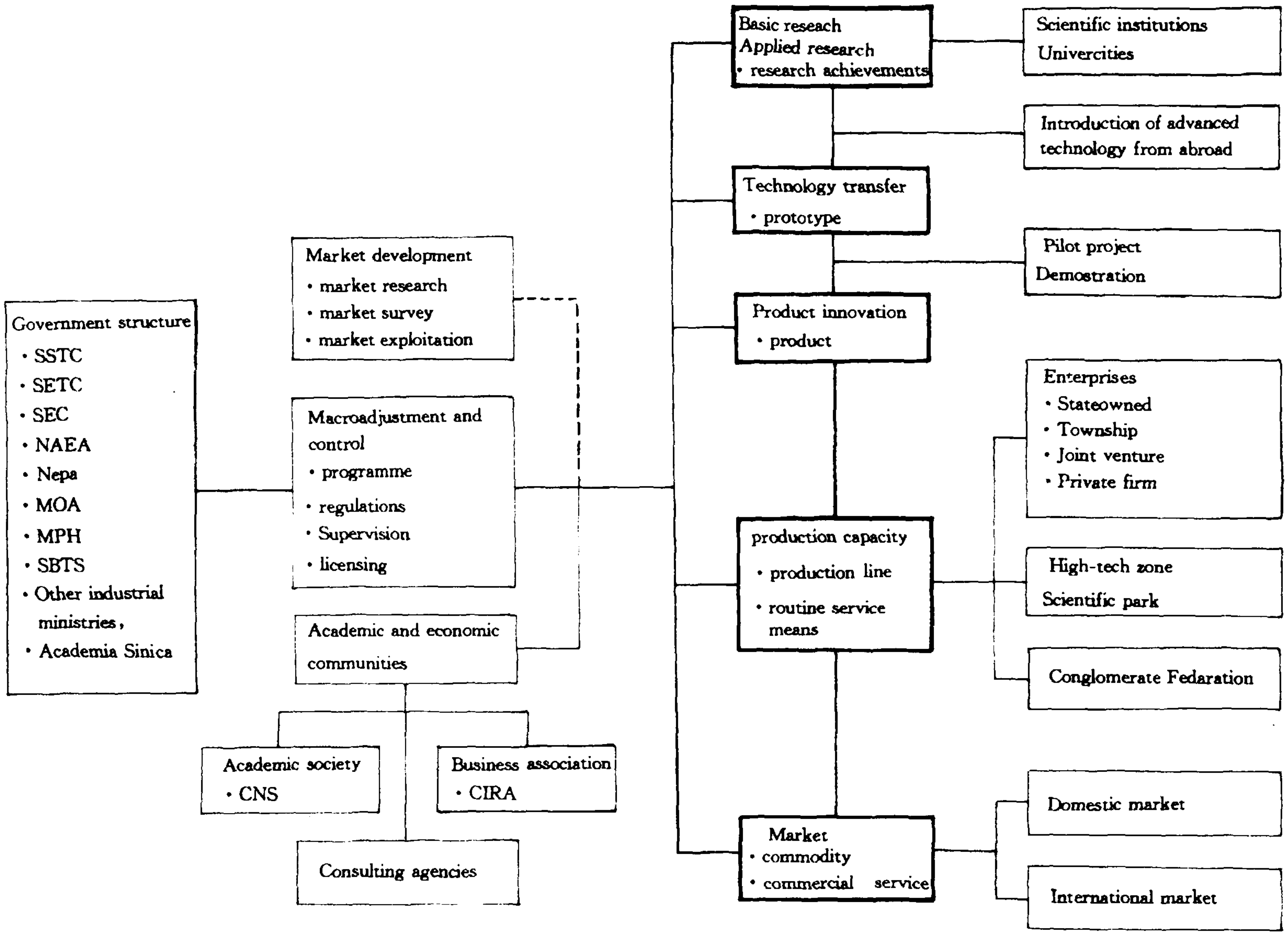

Fig. 1 Scheme for the industrialization drive of radiation processing in China

It is obvious that a successful transfer of technology in the drive depends on the subject of proposed project. Therefore, there must be a careful estimation of the feasibility study which should cover market survey and requirements in the local area, identification of technological pattern and selection of key equipments, analysis and assessment of environment influence, economics analysis and estimation of capital investment including the analysis of risks and sensitivity and the prediction of investment return before making an investment decision on a new project in light of relatively high capital cost of radiation processing. Only with the full run of the capacity of the radiation facilities for processing sufficiently high quantities of products can higher investment and operating cost be accepted by the recipient users of transfered projects on the basis of technological superiority in the industrialization drive of radiation processing. It is expected that the following general criteria may provide greater opportunities for the project identification of technological transfer under the current market situation in China:

——Aiming at the nation's priorities of economic construction such as energy, transport, communication and environment protection;

——Involvement in hith-tech programmes supported by the Government such as " Torch programme" by the State Science and Technology Commission (SSTC) and " High-tech Industrialization Project in Combination with Industries, Universities and Laboratories" jointly organized by the State Economic and Trade Committee (SETC), the State Education Committee (SEC) and Academia Sinica;

—— Requests of traditional industries for upgrading technological level and improving competitive capability of their enterprises in market economy;

——Desiring of industrial investors, particularly oversea investors, to get final economic and commercial success on a basis of technological transfer of radiation processing.

1.3 Roles of various domestic organizations

There have been different domestic organizations and departments, involved in the industrialization drive of radiation processing, with their corresponding roles to play in every link of the drive chain.

1.3.1 Government departments

The roles of the Government departments are crucial in every stages of the drive because they are in charge of administration and supervision. These departments have macroscopically adjusted and controlled the activities of the drive by means of policy, rules regulations, making decision, planning programme and so on, and implemented the special supervision on identification, certification and licensing of the approved or new projects. In fact the successful drive can not be separated from the support and guidance of the Government departments, including SSTC, SETC, SEC, National Atomic Energy Agency (NAEA), National Environmental Protection Agency (NEPA), Ministry of Agriculture (MOA), Ministry of Public Health (MPH), State Bureau of Technical Supervision (SBTS), other industrial ministries, and Academia Sinica. For instance, the establishment of a radiation processing project attached to high-tech industries needs a favourable policy, an overall development plan, and funds for pilot test and demostration, which would have not been realized without the involvement of the Government departments.

1.3.2 Academic and economic communities

Being a bridge and tie between the Government and various industrialized organizations (e. g. enterprises), the academic and economic communities such as Chinese Nuclear Society (CNS), China Isotope and Radiation Association (CIRA) and other consulting agencies have played an important role in the industrialization drive nationwide. Among them the CIRA takes the responsibility for the maintenance of legal rights and interests of its members in addition to the provision of business consultation and background materials for the Government's decision-making in the drive programme[3]. Besides, the Association is assigned to carry out various activities such as training services, scientific and technical meetings, publications, exchange and dissemination of both domestic and overseas information, introduction of advanced technologies and equipments from foreign countries, domestic expert service for enterprise problems, preparation of nationwide technical standards, identification of new radiation processing products and recommendation of excellent domestic products, establishment of network center for product sales and prise coodination to respond to the needs of the Association's members.

1.3.3 Scientific institutions and universities

Scientific institutions and universities in different parts of the country were the pioneers with their findings on basic and applied researches on applications of radiation processing in industry, agriculture and medicine, which were supported by the Government in previous planned ecorcomy. Facing the current market economy, a number of nuclear experts in the institutions and universities have had to learn to be suitable to varying environment. At present, some institutions and universities are playing a distinctive role in the industrialization drive of radiation processing by setting new centers or firms in the local high-tech zones and by assisting enterprises to absorb advanced techonologies, thanks to their research features of exploreness and creactiveness.

A typical example is Changchun Institute of Applied Chemistry (CIAC), Acadamy Sinica in China's North-Eastern Jilin Province, where there is a high-tech firm with irradiation facilities (both cobalt-60 irradiator and electron beam accelerator). On the basis of its own technology (e. g. chemical recipes) the firm manufactures radiation crosslinked heat-shrinkable materials such as accessories for power and communication cables and varieties of sleeves, tubings and irregular shape articles in a large share of domestic market. The firm has become an important center for radiation processing in China[4].

In order to help the scientists and engineers to get upgraded in knowledge and skill and the workers practiced in safety operation, it is necessary to run a programme of personnel training and adult education to satisfy the needs of the industrialization drive. The universities and some institutions should bring their superiorities into full play in this field.

1.4 Recipients of technology transfer

The recipients of technology transfer are usually enterprise organizations, covering state-owned enterprises, township conpanies, joint ventures, private firms, industrial centers in high-tech zones, scientific parks and special economic zones. Sometimes the recipients are even individual farmers (end users). The forms of technology transfer may be both the establishment of new production lines or the commercial services based on domestic research achievements or technology introduced from abroad.

1.4.1 Irradiation centers

During the earlier period of the drive, almost half of the radiation facilities were on a small- and medium-scale and concentrated in the scientific institutions and universities, of which some preferred researches and developments to commercial operation due to lack of the market awareness. In recent years the establishment of radiation centers has provided irradiation services to a number of local small manufacturers at a cost corresponding to the total combined throughput. These centers have in many cases satisfied the needs of small industries where it may not be feasible to justify investment in a single purpose in-house radiation facility.

A successful example was the setting up of Shenzhen Irradiation Center (SIC) in Shenzhen special economic zone near Hong Kong in 1986, when a complete set of modern irradiator was introduced from Canada[5]. Since then, the largest cobalt-60 facility in China has been operating in safety and its productivity has been increasing on a basis of various commercial services. The region superiority of the Center is expected to demostrate the vitality of radiation processing industry and to promote that Shenzhen special economic zone joins hands with neighbouring Hong Kong to develop high-tech industries including radiation processing for ensuring a proporous market.

1.4.2 Traditional industries for survival

In the market economy, a number of domestic traditional industries is managing to be armed with modern technologies to disengage from economic deficits due to lack of competitiveness of routine products.

Changshu Electric Cable Factory (CECF) in Jiangsu Province of eastern China has been a manufaeturer for routine products appointed by both Ministries of Machine Building and Electric Power. With recent price increasing of raw materials and excess production of routine products, the Factory was determined to develop technology-intensive and high value-added products to sharpen its competitive edge in 1992, and with the help of nuclear experts a domestic made electron beam accelerator was installed as a key facility in a new production-line in place of outdated equipment. Since then, various kinds of electric wire and cable insulated with radiation crosslinked polymeric materials have been put into the market. Among them, two new products —— 10 kV radiation crosslinked polyolefine insulated overhead cable and 125℃ flame-retardant radiation crosslinked polyolefine insulated wire were rapidly accepted by the domestic users due to their high quality and special performances and have become famous products. Compared with other rivals in the competitive market, Changshu Factory has enjoyed its technical superiority by a considerable market share for the survival[6].

There are more examples, similar to above mentioned Changshu Factory, in different parts of the country. The industrialization drive of radiation processing can not only revitalized the enterprises with technology, but also speed up the technological transformation of traditional industries.

1.4.3 Interested farmers (end users)

Domestic research achievements in the field of the application of radiation processing for foods and agricultural products have made Chinese farmers the end users of technology transfer. Irradiation with low dose is effective on sprout inhibition of root crops such as potatos, onions, garlic, ginger-root when the treatment is carried out in their dormant state (e. g. within one month after their harvest). For instance, the shelflife extension of irradiated garlic on the basis of sprout inhibition has led to the full confidence of Chinese peasents, especially in the poverty-stricken areas, in planting garlic in a large area of field to ensure the demands in the domestic and overseas markets. In fact, there has been a shift of rural economy from poor to rich in some counties of central China only by the introduction of the modern technology[7]. At present more and more Chinese farmers are interested in radiation processing used for the treatment of agricultural products. Even some individual farmer investors are being inspired to set up their own radiation facilities for the prospects of economic success. Their enthusiasm for radiation processing is often stopped after the feasibility study or the project identification by the lack of infrastrusture and the seasonal availibility of agricultural products.

2 INDUSTRIAL RADIATION FACILITIES

Reliable and less expensive radiation facilities have been considered as a frame foundation in the industrialization drive of radiation processing. In China there has been formed a network consisting of various types of industrial radiation facilities for radiation processing installed in different parts of the country. Among them, the facilities with cobalt-60 gamma-ray source and electron beam accelerator are dominant in number as compared with others, including a large-scale gamma-radiation field using spent fuel elements from a nuclear reactor, a transportable irradiator with caesium-137 and so on. The present capability of national nuclear industry can ensure the most of various requirements for the types and sizes of radiation facilities, covering design, manufacture, installation, commissioning, operation and so on. The insufficient part has to be complemented with the introduction from abroad.

2.1 Cobalt-60 gamma-ray facilities

Cobalt-60 gamma-ray facilities are the most popular among all the radiation facilities in China, which consist of the major components of cobalt-60 source, radiation shield, source-handling mechanism, source containment and product-handling equipment. According to statistics, there are nearly 50 cobalt-60 gamma-ray radiation facilities, with designed capacity more than 11.1 PBq (300 kCi) each, distributed in about 40 cities of 22 provinces, autonomous regions and municipalities (see Table 1). The total designed capacity of cobalt-60 gamma-ray facilities is estimated at 1.3 EBq (35 MCi), and the total loaded capacity is 296 PBq (8 MCi) throughout the country. The growth of total cobalt-60 capacity during the last decade is shown in Fig. 2.

Table 1 Regional distribution of industrial gamma-ray facilities with designed capacity of cobalt-60 more than 300 kCi in China[8]

Areas	Provinces, autonomous regions and municipalities (number)	Total number (percentage)
North	Beijing (4), Tianjin (1) Hebei (2)	7 (≈15%)
East	Shanghai (3), Shandong (4), Jiangsu (3), Zhejiang (3) Fujian (3), Jiangxi (1)	17 (≈35%)
Central and south	Henan (3), Hubei (2), Hunan (1), Guangdong (2), Hainan (1)	9 (≈19%)
Northeast	Heilongjian (2), Jilin (3), Liaoning (4)	9 (≈19%)
Southwest	Sichuan (2), Yunnan (1)	3 (≈6%)
Northwest	Shaanxi (1), Gansu (1), Xingjaing	3 (≈6%)
Whole country		48 (≈100%)

As mentioned above, the largest gamma-ray facility is in SIC, Shenzhen special economic zone with a irradiator of designed capacity of 148 PBq (4 MCi) cobalt-60 and the loaded capacity 40 PBq (1.1 MCi) from Canada. There are half of the total number of the facilities located in the coastal areas of China. Domestically made cobalt-60 irradiators are of small- and medium-size with features of single-plate-source or double-plate-source for multipurpose[9].

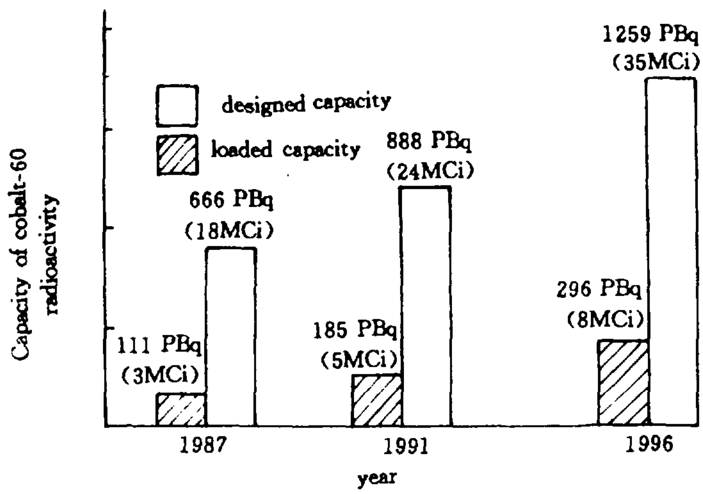

Fig. 2 Growth of total capacity of cobalt-60 radioactivity in gamma-facilities during recent decade in China

With a large penetration and relatively low intensity of gamma-rays compared with electron beams in accelerators, cobalt-60 facilities are more suitable to be used for the irradiation of large volume packagings and irregular shaped products. It is estimated that among the market shares of gamma-irradiated products, 40% is contributed by radiation initiated chemical processing, 40% by the radiation sterilization of medical products, 10% by irradiated foods and 10% by the others.

2.2 Production of cobalt-60 source and practice of a gamma-radiation field with spent fuel elements

The broad gap between total designed and loaded capacities in existing cobalt-60 gamma-ray facilities has shown the great potential of radiation processing nationalwide and the strong requirement of cobalt-60 source in the future. At present, the domestic production of cobalt-60 source can only satisty partial demands of all existing facilities. Nuclear Power Institute of China (NPIC) in Sichuan province of southwest China is the most important base of cobalt-60 production with a High Flux Engineering Test Reactor (HFETR) of heat power 125 MW and maximum thermal neutron fluence rate 6.2×10^{14} n/ ($cm^2\cdot s$). The specification of cobalt-60 source sealed inside a double stainless steel capsule depends on its varied purposes (e. g. therapy, radiography, instrument and industrial uses). The specific activity of industrial sources is 1.11~1.85 TBq/g with safety performance in compliance with general requirements of the State Standard and International Standard Organization (ISO)[10]. In a typical irradiator the cobalt-60 source is usually installed in a source rack to form a suitable geometry and then has to be refreshed at the rate of 12.3% per year. A shortage of domestic supply of colbat-60 has been made up by imported source from such countries as Canada, England and Russia in spite of higher price.

Just at the same place (NPIC) there is a large gamma-radiation field with spent fuel elements from the nuclear reactor (HFETR). The gamma-ray activity of the spent elements which were from the reactor operated with a power of 50 MW for 30 days and had been cooled for 150 days was equivalent to 37 PBq (1 MCi) cobalt-60. A two-well shaped structure around arranged by spent fuel elements in water pool established the gamma-radiation field in 1983. This type of radiation field is actually a complex gamma-source of mixed radioisotopes with a variable half-life and an inconstant energy spectrum but without any harzard of radioactivation induced by residue neutrons in irradiation processed products. The practice has proved that the gamma-radiation field can be used as a special irradiator for routine applications such as radiation crosslinking of polyethylene and radiation processing of polytetrafluoroethylene. Up to now, the batch-production of heat-shrinkable materials in the gamma-field has successfully got some economic benefits.

2.3 Electron beam facilities

Electron beam facilities are another main category of radiation facilities with the major components of an electron beam accelerator, shielding and product-handling equipments. Among them, the accelerator can be considered as a radiation source of high energy electrons generated by itself for industrial scale processing.

Basically, there are several different ways to accelerate electrons and, consequently, different designs of accelerators, auch as electrostatic generators, resonance transformers, insulating core transformers (ICT), Cockcroft-Walton accelerator, Dynamitron, microwave linear accelerator (linac) and resonance cavity accelerator with a wide range of performance ratings. Only a few of them would be suitable for a particular application.

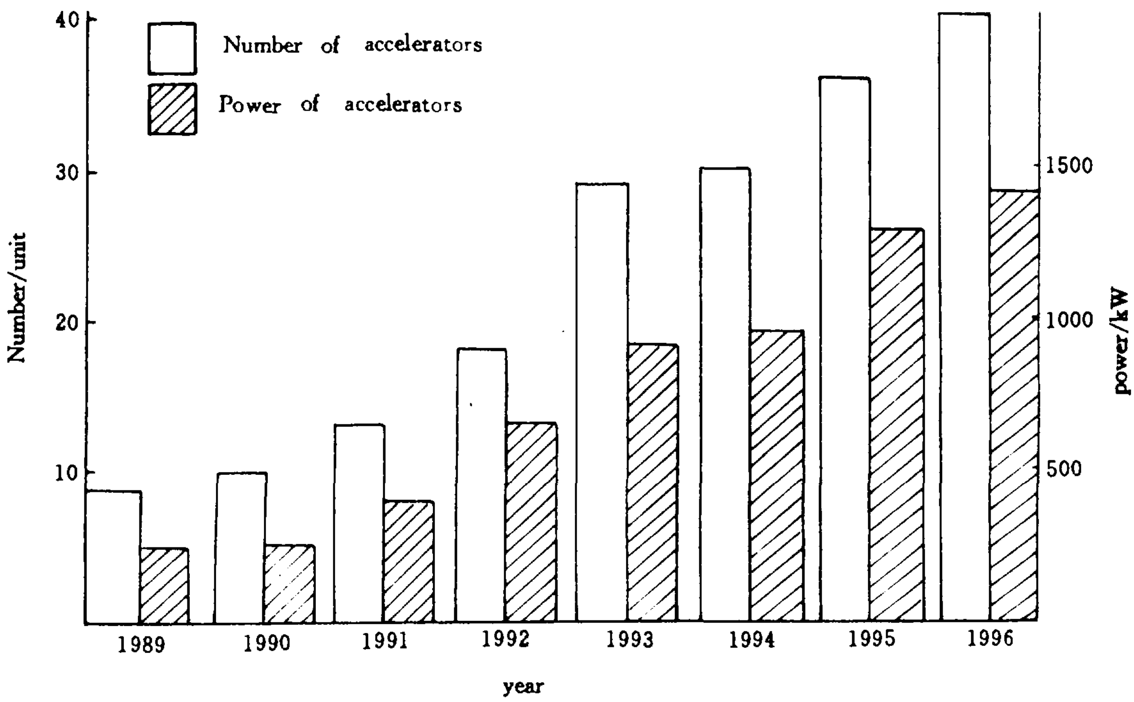

Fig. 3 Growth of total number and total power of electron-beam accelerators in China

With the recent development of radiation processing, the number and total power of electron beam accelerators (both domestic and imported) have rapidly increased. (Fig. 3). According to a survey in the early 1996 there were about 40 industrial electron beam accelerators of different types with a total power of about 1400 kW, distributed over 18 provinces, autonomous regions and municipalities (Table 2)[12]. Among the existing industrial electron beam accelerators, most of them were domestically made by several manufacturers, and the rest was imported by powerful enterprises from foreign countries such as the United States, Japan, Russia and France. Domatically made accelerators can be basically devided into two types, namely highvoltage and resonance (Table 3). The most important production base of industrial electron beam accelerator in China is Xianfeng Electric Manufacturing Works (XEMW) in Shanghai which has supplied more than 60 accelerators of different types for over four decades. At present a type of high frequency and high voltage accelerator has become a recommended equipment in the field of radiation processing. Domestically made accelerators have easily been accepted by a number of vital enterprises in the small and middle cities because of their low-price, good after-sale service and convenient maintance, and even have been exported to abroad (Indonesia).

Table 2 Regional distribution of industrial electron beam accelerators in China

Areas	Provinces, autonomous regions and municipalities (number)	Total number (percentage)
North	Beijing (1), Tianjin (2), Hebei (2), Shanxi (1)	6 (≈15%)
East	*Shanghai (6), Shandong (2), Jiangsu (5), Zhejiang* (2), Jiangxi (1), Anhui (1)	17 (≈42%)
Central and south	Hubei (1), Guangdong (2)	3 (≈8%)
Northeast	Jilin (3), Liaoning (2)	5 (≈12%)
Southwest	Sichuan (5), Yunnan (1)	6 (≈15%)
Northwest	Shanxi (1), Gansu (2)	3 (≈8%)
Whole country		40 (≈100%)

Table 3 Types of domestically made electron beam accelerators and their performance

Type		Energy MeV	Beam current mA (W)	Scanning wide mm	Electric power eff. %	Frequency of power supply/Hz
D. C. high voltage single accelerator	Insulating core transformer (ICT)	0.3	30	1000	80	50
		0.6	40～50	1000	80	50
		1.2	10	800	80	50
	High frequency cascade generator	2.0	10	800	40	100×10^3
		2.5	20	1000	40	100×10^3
	Medium frequency multiplier	0.5	30	1000	60	2000
	Long filament type	0.2	20	450	80	50
Pulsed resonace accelerator	Single cavity standing wave linear accelerator	2.0	10	800	20	110×10^6
	Travailing wave electron linear accelerator	5.0		660	20	3000×10^6
		10.0		600	20	3000×10^6
		20.0		400	20	2856×10^6

In order to guide the production of different manufacturers in China," General Guidance of Electron Accelerator for Radiation Processing" (EJ/T 971-95) was documented with items, covering type classification and designation, technology requirements, identification methods and rules, packaging, transporting and storage for various equipments of energy range 0.15～15 MeV to ensure the quality of domestically made accelerators.

Being a category of industrial radiation facilities with the short radiation penetration and the high intensity, electron beam accelerators are suitable to the treatment of plastics, rubber products and high volume streams of material (e. g. waste) with high throughput rates. The existing aecelerators are mainly used in production lines at different enterprises for the production of heat shrinkable materials (50%), wire and cable (35%) and others (15%) in China.

2.4 Efficient utilization of radiation facilities

In the industrialization drive, the sufficiently large scale applications of radiation processing lie on industrial radiation facilities (cobalt-60 irradiators or electron beam accelerators), which should be flexibly used in the operation on either a batch or a continuous mode (on-line), as well as on a service (contract) basis. As shown by practice, radiation processing has the superiority over many competitive techniques in the sense that it can always be tailored to actual needs in terms of throughput. For instance, a cobalt-60 facility's product-handling equipment and radiation shielding can be designed for desired output, while the actural loading of cobalt-60 is made to satisfy the existing need. In the future time, more cobalt-60 can be added to the irradiator easily to adapt to a growing capacity.

Generally, the acceptable investment and operating cost of industrial radiation facilities can be expected to bring the economic return of the technical and technological merits and the higher quality of processed products. This has been clearly indicated by the successful operation of various facilities and a great volume of radiation processed products for many years in the different parts of the country. Therefore, more and more Chinese non-nuclear experts and enterprisers have a strong interest in arming the existing production lines with advanced industrial radiation equipments in their factories.

Accelerators are often considered to be of competitiveness against cobalt-60 sources in the industrialization drive of radiation processing. At least, unlike gamma-ray facilities, electron beam installations will have no radiation once the high voltage is turned off. However, in the developing countries it is difficult to make a comparison between the two kinds of radiation facilities, because they are technologically complementary in many cases with their own features (Table 4). The operation of gamma-ray facility seems to be simpler and more reliable than electron beam accelerator because the competent personnel with professional knowledge is needed for the latter's operation and maintainance. In fact, for cobalt-60 gamma-ray facilities the utilization efficiency mainly depends on the absorbed dose of processed products which is determined by the source-product geometry, product density, source activity and total time of irradiation. It is clearly to be seen that the first three parameters are normally constant, thus the irradiation time becomes the chief controllable parameter. Therefore, this is why at present time the number of cobalt-60 irradiators including small-scale ones is much more than electron beam accelerators in China. Unfortunately, not all of existing facitities are being fully utilized, some facilities with the avarage operation time below 5000～6000 hours per year are often from lack of the careful estimations on the feasibility study of the proposed project.

Table 4 Comparisons of radiation characteristics between two categories of radiation facilities

Characteristics	Gamma-rays	Electron beams
Energy	1.17+1.33 MeV	0.2～10 MeV
Power	1.48 kW/3.7 PBq	1.5～400 kW/unit
Dose rate	low (10 kGy/h)	high (10 kGy/s)
Penetration	high (43 cm in water)	low (≈0.35 cm/MeV)
Energy utilization efficiency	low (≈40%)	10%～90%
Production rate	low	high
Maintenance	replenishment of source (decay 12.3% per year)	professionals with special knowledge

The successful and less successful experiences and even the outright failed lessons learned from the industrialization drive over past several decades have created a wealth of information about factors influencing the utilization efficiency of radiation facilities, especially of gamma-ray installations. The following factors were identified beyond ambiguity:

——Minimum investment for the capital construction of a radiation facility.

——In compliance with regulations concerned, the safety and reliable operation with a maximum availibility of ranning time in an industrial environment.

——Optimum geometry of gamma-source and perfect arrangement for the irradiation position of various products.

——Reasonable technological process of getting minimum absorbed dose of the products with homogeneous dose distribution to ensure sufficient irradiation efficiency, defined as the ratio of the amount of absorbed radiation by the product to the total amount of radiation dose, emitted from the source.

——Unification and generalization of packaged unit size for various products and specification of facility operation for single purpose in favour of large scale production.

—— Business management strategy of industrial applications for expanding market opportunities along with efforts made in the integration of research, production and sale.

3 MAIN APPLICATIONS AND MARKET POTENTIAL

In the process of the industrialization drive of radiation processing there have been some main applications carried out in various parts of the country, including modification of plastics, polymerization, food treatment, medical sterilization, curing of surface coatings, and others. Some have formed the routine or pilot manufacture with high-tech products put into the market to fullfil the domestic demands (Table 5). Of them, three radiation processed products are of the greatest importance in the market share at present and they are crosslinked heat shrinkable materials, crosslinked wire and cable insulators, and latex-polymerized auxiliary agents for textile printing and dyeing[14].

Table 5 Main applications of radiation processing in China

Application	Place of Production	Radiation Source
Heat shrinkables	Sichuan, Jilin, Guangdong, Jiangsu Shanxi	accelerator cobalt-60 gamma-field
Wire and cable insulators	Shanghai, Tianjin Shandong Jiangsu Liaoning, Beijing, Shanxi, Gansu	accelerator
Textile printing and dyeing auxiliary agents	Anhui, Beijing, Jiangsu	cobalt-60
Polyacrylamide (PAAM) for oil industry	Heilongjiang	cobalt-60
Soft contact lenses	shanghai, Jiangsu	cobalt-60
Bettery membrance	Shanghai	cobalt-60
PTFE powder for lubracator	Shanghai, Beijing, Tianjing, Sichuan	cobalt-60 accelerator
Regenerated polyisobutylene rubber	Jilin	aceelerator
Artificial skin for medical uses	Shanghai	cobalt-60
Medical products	Beijing, Guongdong, Jiangsu	cobalt-60
Agricultural products and foods	Henan, Shanghai, Shandong, Jilin, Jiangsu, Beijing, Zhejiang, Guang-dong, Heilongjiang	cobalt-60
Modification of silicon semiconductor	Beijing, Tianjin, Sichuan	accelerator nuclear reactor
Colouring of jade	Beijing, Sichuan, Jiangsu	cobalt-60 accelerator
Curing of surface coatings	Shanghai, Sichuan, Beijing	accelerator

3.1 Heat shrinkable materials

The manufacture of heat shrinkable materials on a basis of domestic chemical recipes is the most successful industrial application of radiation processing in China. The materials show rubberlike properties at temperature above the melting point due to being radiation crosslinked. When heated, it is deformed. And by cooling its deformed shape or expanded size is maintained indefinitely until it is reheated when it tends to return to its original shape and size. The phenomenon is called a "memory effect" and is applied in the production of heat shrinkable film, tubing, tape etc. There are four main categories of current products, including electric power, communication, electronics and oil industry, with more than 300 specifications seized the largest domestic market share among various radiation products. These products are usually used for the accessories of power cables and telecommunication cables, food packaging materials (film and foil) , wrapping and insulation of the connections of telephone cables and electronics, anticorrosion wrapping for oil pipelines and so on. It is encouraging that some of the products have been exported to the foreign countries in South-East Asia and Middle-East regions.

With the development of national economy, there must be increasing demands for various heat shringkable products in China. Therefore , it is necessary that the efforts are made to upgrade quality and to increase the yield and the kinds of the domestic products for the future market supply.

3.2 Wire and cable

More and more Chinese enterprisers in the wire and cable industry have recognized that radiation crosslinking of the insulators is an effective means for improving wire and cable products' qualities such as thermal resistance, abrasion resistance, tensile strength, and so on. These products are generally used in electrical appliances, cars, the aerospace industry, computers, communications (e. g. telephone swichboards) and many other low and medium voltage applications. The increasing number of electron beam accelerators in recent years for this purpose have proved the prospects and vitality of radiation processing in the technological transformation of conventional processes for wire and cable industry.

However, it should be seen that the annual output value of domestic radiation crosslinked wire and cable only accounts for 10% of all routine products in China, which is still very low as compared with more than 50% in other developed countries in the world [12].

3.3 Printing and dyeing auxiliary agents

Another important radiation processed product is a series of latex polymerized agents by colbat-60 irradiation used for the printing and dyeing auxiliary agents in textile industry. Practice has shown that these products have the advantage of the thickening effeciency to be better than other conventional products processed at ambient temperature. It is estimated that the annual throughput is about 3000 tons manufactured at 6 cities in the country[15].

3.4 Irradiated foods

Chinese nuclear experts have been pursueing the transfer of the food irradiation technology to the food industry and trade in their research and development activities for a long period. National authorities have been concerned about foods preservation against the spoilage. By using radiation method pathogenic microorganisms, insects and parasites can be destroyed and the physiological process of ripening and maturing of a large variety of food items can be slowed-down, which would reduce the postharvest losses of food and agricultural products and improve public health in terms of decrease of food-borne diseases, and facilitate wider distribution of food in trade. The successful nationwide programme of research and development on food irradiation, including technology feasibility, animal toxicity test, human trails of consumption, clearing procedure and hygienic standard, market testing and others, has promoted the commercial application. It is estimated that the total production of irradiated foods (particularly garlic) amounted to more than 20 000 tons per year in China. By referring to the recommendations put forward by FAO/IAEA/WHO Joint Expert Committee and the experiences of other countries, the legislation inspection and clearing regulations are being perfected to further the commercial activities of food irradiation. It is quite definite that the potentialities of radiation treatment of foods are immense since more foods are needed to satisfy ever-increasing population in China.

3.5 Sterilization of medical products

On the domestic market only a small percentage of all disposable medical products is sterilized by radiation in various multipurpose gamma-ray irradiators in different cities, while the ratio in developed countries has reached to 50% and this method has been considered as one of the most successful industrial applications of radiation processing in the world. The reason why radiation sterilization of domestic medical products has not become a commercial business is from lack of economic competitiviness as compared with common chemical method of ethylene oxide gas which is run at relatively low cost in China.

It is expected that radiation sterilization capacity will have a significant increase in the near future thanks to formulating of stricter regulations for manufacture and sterilization of medical products in accordance with international recommedations (ISO) which will lead increasing cost of gas sterilization method with the required improvement of process quality control to eliminate consequent high risks for workers and patients. Besides, a successful commercialization of radiation sterilization also depends on the development of domestic materials used in product manufacture which should be of stability for radiation processing.

In addition to the main applications described above, other important ones, such as disinfection of Chinese medicinal herbs, sterilization of pharmaceuticals, synthesis of biomaterials (biocompatible and immobilized bioactive species), crosslinking of plastic foam, vulcanization of natural rubber latex, curring of surface coatings, processing of composite materials, treatment of industrial pollutants (flue gases and sewage sludge) and biomass conversion, have still limited in laboratory researches, some of which have been put to pilot scale tests. It is expected that the prospect of commercial applications of those projects will be highly promising, as the economic boom is continueing in China.

4 CONCLUSION

Rapid economic growth accompanied with an increasing demand for access to the benefits of modern technologies has provided golden opportunities for radiation processing to be a market-oriented technology with economic viability. For many years, the common efforts from every organization and department concerned have been focused on the nationwide industrialization drive for radiation processing, which is aimed at the transfer of research and development achievements to routine applications, in order to emerge as the high-tech industry, modernize the traditional industries, and offer the commercial services. At the present time, it can be said that a new radiation processing industry is shaping up in its developing stage in China.

However, it is clear that there is a large gap in the industrial scale and product varieties of domestic radiation processing while compared with these in developed countries in the world. In order to satisfy the increasing demands for economic boom on a large domestic market with a population of 1.2 billion and vast territories in China and to improve the present infrastucture for the industrialization drive of radiation processing to cope with the world's competitive economy, international exchange and cooperation must be enhanced.

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