The progress of radioisotope technology and application in China

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Abstract: The inception of radioisotope and its application in China are introduced. The research, development, production, application progress and the future development prospect of radioisotope and its products are described.

Key words: atomic energy science and technology in China; radioisotope; preparation technique and application

1 Introduction

Radioisotope technology is a comprehensive high technology which deals specially with the research of special property, preparation and application of radioisotopes on the basis of the theory of nuclear physics, radiochemistry and related subjects; and it is an important part of nuclear science and technology.

Since over half of the century after the second world war, radioisotope technology and application have fully demonstrated its unique superiority, i. e. its advanced nature, non-replaceability, cross-permeability and extensiveness of application, in a lot of fields such as ensuring the national security, deepening agriculture green-revolution, promoting industry modernization, driving forward the development of environmental protection undertaking and improving the mankind's ability to conquer diseases. As pointed out by the International Atomic Energy Agency (IAEA) in one of its bulletins, "... In so far as the scope of application is concerned, maybe the application of modern electronics and computers could only be mentioned in the same breath with it."

2 A brief review of the history

In the early period after the founding of new China when our country planned and prepared the national development program of atomic energy science and technology, the radioisotope technology and application was considered to be brought into the program. In 1956, the atomic energy science and technology as an important developing project was placed on the long-range developing plan for 12-year science and technology established by our country, of which radioisotope technology and application was listed as one of main contents. Since then, radioisotope technology and application has been grown in China.

At that time, a collection of Chinese science and technology personnel joined the ranks of radioisotope technology and application work one after another, among them there were some returned scholars who ever studied in Europe and America and in former Soviet Union, the university students and postgraduates who were trained at home, as well as some science and technology personnel who were transferred from other departments. Those science and technology personnel later gradually became the mainstay and backbone force in developing the radioisotope technology and application through study, being trained and being tempered in undertaking.

In 1958, the first heavy-water reactor and the first cyclotron of our country which were built with the help of former Soviet Union were put into operation in the China Institute of Atomic Energy (CIAE). That institute was successful in developing first 33 kinds of artificial radioisotopes by use of that reactor, thus starting the undertaking of radioisotope technology and application in China.

In 1967, the swimming-pool light-water reactor which was built from our country's own design and the first radioisotope research laboratory were built up at the same time in the CIAE, then the research work on radiopharmaceutical, labeled compound, radioactive source and quality control method was systematically carried out. Since 1970s, in order to meet the domestic growing needs for radioisotope, the institute has successively completed some production facilities with the support of the state. They were: the development and production facilities of radioisotope for medical use and radioactive source for industrial use which were

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completed in 1972; the development and production facilities of radioimmunoassay (RIA) kits and labeled compound as well as the development and production facilities of radioactive source for industrial use in 1982; the development and production facilities for extraction of ^{99}Mo from fission products, the ^{99}Mo–^{99m}Tc generator and its complementary kits in 1995; an advanced cyclotron and its radioisotope pharmaceutical development and production facilities which were completed by the CIAE in cooperation with a company of Belgium in 1996.

By the midterm of 1990s, the radioisotope and its products of the CIAE had developed and produced by use of the reactor and cyclotron amounted to approximately 200 kinds on an accumulative basis. The product categories were by and large complete and the achievements in the preparation technology were the largest in quantity throughout the country. The products provided by that institute were extensively applied in nuclear medicine, industry and related fields of our country.

In 1997, Jiuquan Atomic Energy Complex completed the radioisotope development and production facilities and the pilot-workshop of ^{90}Sr, ^{137}Cs and ^{147}Pm making use of actinide elements separated from spent fuel post-processing and of radioisotopes from fission products. That Complex has successively developed and produced such products as tritium lamp, tritium-luminescent powder, Krypton (^{85}Kr) lamp, ^{147}Pm-luminescent powder, ^{241}Am-smoke detector source, ^{238}Pu-static electric eliminator, ^{241}Am-Be neutron source, ^{238}Pu-Be neutron source and ^{137}Cs radiation source.

In 1982, the Nuclear Power Institute of China (NPIC) completed the reactor radioisotope production facilities. That institute used a high-flux reactor and a light-water reactor of its own to successively develop and produce some radioisotopes such as ^{131}I, ^{125}I, ^{32}P, ^{89}Sr and other products such as the gel-type ^{99}Mo–^{99m}Tc generator, ^{113}Sn–^{113m}In generator, ^{99m}Tc-MDP(Yunke), ^{60}Co and ^{192}Ir strong radiation source for use in industry and medicine as well as some RIA kits.

In 1980s, the China Academy of Engineering Physics was engaged in research work on radioisotope and its pharmaceutical by use of a light-water reactor of its own, and developed and produced some products such as ^{241}Am smoke detector source and tritium-titanium target.

Since 1970s, Shanghai Applied Physics Institute under the China Academy of Sciences has been engineering in the development and production of the radioactive labeled compounds with ^{3}H, ^{14}C, ^{35}S and so on; in the midterm of 1980s, the institute also developed and produced the nucleotides labeled with ^{35}S and some RIA kits.

In the early 1990s, Shanghai Applied Physics Institute completed the cyclotron radioisotope and its pharmaceutical production facilities, through Shanghai Kexin Pharmacy Company which was set up on joint stock and by use of a cyclotron introduced from IBA company of Belgium, mainly developing and producing SPECT and PET imaging pharmaceuticals by use of the cyclotron, and being also engaged in the development and production of ^{188}W–^{188}Re generator and $^{89}SrCl_2$ injection and so on.

By the midterm of 1990s, a relatively complete radioisotope and its product development and production system had been basically formed in our country, which included the radioisotope produced by use of reactor and cyclotron, the radioisotope product for medical use and its pharmaceutical, the radioactive source for industrial use and the radioactive tracer.

Here it needs to be specially pointed out that during the course of the radioisotope technology system in our country being formed, many universities and scientific research institution engaged in related research work in our country have also made a contribution to it with their own much technology achievements and experience accumulated.

For instance, besides the CIAE, Lanzhou Modern Physics Institute under China Academy of Sciences which was at the earliest engaged in cyclotron radioisotope developing work in our country as well as some units which possess cyclotron such as the Institute of High Energy Physics, the Automation Institute and Sichuan University have also carried out a lot of research works on radioisotope preparation by use of cyclotron, laying down a technological foundation for the cyclotron radiopharmaceutical and related radioactive source preparation in our country.

In addition, many universities, scientific research institution and hospitals involving such fields as biology and medicine have also carried out plenty of fruitful research work for the development of the radiopharmaceutical and RIA kits preparing technology at home, which won't be enumerated one by one here.

The progress in radioisotope development and production of our country has greatly promoted the development of its application to agriculture, industry, medicine and some related fields.

Soon after "one reactor and one accelerator" were completed in the CIAE, several professional isotope laboratories such as the research center on atomic energy utilization in agriculture, the laboratory on isotope for use in metallurgy and the laboratory on gamma flaw detection were also set up one after another with the assistance of the former Soviet Union.

Soon afterwards, some research units and factories engaged in the development of nuclear instrumentation and nuclear control system established their own isotope laboratory one after another, thus promoting the broader application of radioisotope in our country.

The application of radioisotope technology in agriculture began from 1956 in our country. By the midterm of 1980s, the application in the following two aspects had mainly been carried out.

One is the radiotracer application. For instance, Zhejiang Agricultural University etc. started from 1963 to research by use of radiotracer the organic arsenic, phosphorus, nitrogen and sulfur residuals of pesticide in such crops as rice and fruit tree and in the soil as well as degradation law, with the aim of providing scientific basis for formulating the safety standard of pesticides. Besides, during 1970 to 1980, the Institute of Atomic Energy Application under China Academy of Agricultural Sciences collaborated with Beijing University to research the synergistic effect of humic acid on phosphate fertilizer and its formula using ^{32}P as tracer, the research result being used for humic nitrogen-phosphorus compound fertilizer production in our country.

The other is the application of ^{60}Co radiation source. In the late 1950s, the agricultural sectors of our country started to use ^{60}Co radiation source to carry out research work including gamma radiation breeding, food radurization, promoting plant growth and development as well as pest control by use of sterile insect technique, and obtained a lot of application results which have important economic and social benefits. Among them, the results obtained in radiation breeding have made our country one of those countries among the member states of the IAEA which have most varieties of radiation breeding and in which the application has been the most widely popularized.

Since the early 1970s, the development and application of radioimmunoassay (RIA) kits have been started in our country. By the midterm of 1990s, nearly a hundred kinds of RIA kits had been developed and produced, which had been widely applied the hospitals and had become a sensitive and reliable technique for analyzing in vitro super-micro amount of biological substances in human body, having played an important role in disease diagnostic, survey and screening. The development and application of radiopharmaceutical produced by use of reactor began from 1960s in our country. In the late 1960s, owing to the import of radioisotope for medical use being stopped and the urgent needs in nuclear medicine clinical application, our country successively developed, produced and supplied more than 10 kinds of radioisotopes for medical use and their products, thus settling that extremely urgency in domestic nuclear medicine clinical application.

In 1986, the enterprises and institutions producing and managing radiopharmaceutical throughout the country implemented "Pharmaceutical Management Law of the People's Republic of China" and carried out the production and management licensing system, which made China's radiopharmaceutical production and management gradually placed on a legal track.

During the late 1980s to the midterm of 1990s, the fission ^{99m}Mo (feed solution) with high activity, $^{99}Mo-^{99m}Tc$ generator and its complementary pharmaceuticals as well as cyclotron pharmaceuticals $^{201}TlCl$ injection and ^{67}Ga-citrate injection which were developed and produced by our country entered into the clinical application of SPECT imaging diagnosis of the domestic nuclear medicine one after another, thus carrying forward nuclear medicine of our country to a new developing stage of modern nuclear medicine.

As early as the early 1950s, the Ministry of Water and Electricity and the Ministry of the First Machine Building Industry of our country ever adopted gamma-defectoscope to inspect inner flaw of metal component, but its industrial application on a larger range began from 1970s. It was mainly applied to such departments as metallurgy, water conservancy, petroleum, chemical industry, machinery and electronics, with some important application results obtained.

For instance, metallurgy department of our country used ^{45}Ca and ^{95}Nb as tracer to settle the calcium impurity content control in steel and iron products as well as some key technical problems in niobium extracting technology respectively.

In addition, the water conservancy department of our country applied ^{131}I tracer technique to diagnose the risky reservoir dam-body leaking, and also used some radiotracers to research mud and sand movement pattern so as to provide the guidance for dredging river course and harbor and so on.

In 1980s, the Daqing oilfield applied ^{131}Ba microsphere the CIAE developed and produced instead of former ^{131}I solution tracer to establish a logging method with Chinese characteristics, i. e. determining the water-absorbing profile to guide oil extraction. This logging method was extended and applied in the oilfields on land throughout the country and the application results won a second prize of the National Science and Technology Press Award.

All nuclear instrumentation and nuclear control system (NCS) for industrial use in our country need to use various sealed radioactive sources.

The development of radioactive sources in our country began from 1960s. The CIAE launched from the 1970s the research work on radioactive source preparing technology in consideration of the urgent needs of the domestic industrial departments for diversified radioactive source application, and developed and produced about 20 kinds of radioactive sources. In the early 1980s, our country issued the sealed radioactive source standard, which made the quality of radioactive source raised to a new level, thus making an important contribution to the extension and application of nuclear instrumentation and nuclear control system for industrial use in our country.

3 The progress of radioisotope technology and application in China

3.1 The progress of the research and production infrastructure including reactor and cyclotron

In recent years, the construction of research and production facilities such as reactor and cyclotron as the basis and pillar of radioisotope technology development in China has made important progress.

3.1.1 Reactor

Today, there are four reactors in operation which can be used for radioisotope preparation. They are respectively: a Heavy-Water Research Reactor (HWRR) and a Swimming-Pool Reactor (SPR) in CIAE; a High Flux Engineering Test Reactor (HFETR) in the Nuclear Power Institute of China; and the Minjiang Test Reactor (MJTR). Their maximum powers are respectively: 15 MW, 3.5 MW, 125 MW and 5 MW. Their maximum neutron fluxs are respectively: 8×10^{13}, 4×10^{13}, 6×10^{14}, 8×10^{13} ($s^{-1}\cdot cm^{-2}$). There are two reactors in construction which can be used for radioisotope production and expected to arrive at critical conditions in 2008. Among them, the China Advanced Research Reactor (CARR) in construction in the CIAE has a maximum power of 60 MW and a maximum neutron flux of 8×10^{14} ($s^{-1}\cdot cm^{-2}$).

3.1.2 Cyclotron

There are two cyclotrons in operation which are specially used for radioisotope preparation in China. One was constructed by the CIAE in cooperation with Belgian IBA Company; the other was the cyclotron of the same type introduced by Shanghai Amersham Kexin Pharmacy Company from Belgian IBA Company. The proton energy of both are 16 ~ 30 MeV in the continuously adjustable range; the maximum current beam of both is respectively 340 μA (internal target) and about 400 μA (external target bi-directional total). Beijing Normal University, Sichuan University, the Institute of High Energy Physics and Lanzou Institute of Modern Physics also have their own cyclotrons or accelerators to be used for scientific research on radioisotope; By March of 2007, the accumulative total 42 baby-cyclotrons had been installed throughout the country which are complementary to PET and are mainly used for preparing some short lived radioisotopes emitting positron including ^{11}C, ^{13}N, ^{15}O and ^{18}F and their related pharmaceuticals.

3.1.3 Other facilities for the research and production

The other facilities for radioisotope research and production in China are mainly concentrated in Beijing, Chengdu and Shanghai which possesses reactor or cyclotron. In 1998, the State Science and Technology established the State Engineering Technology Research Centre for Isotope in the Department of Isotopes, CIAE. In 2007, the State Ministry of Education established a key laboratory in the radiopharmaceutical field under that Ministry in Beijing Normal University. In addition, some universities, institutions, enterprises have also established respectively specialized laboratories with which the radioisotope research and production can be carried out.

In 1998, the radioisotope industry in China began to establish the quality system in accordance with ISO 9000 series standard, which is now being implemented all-round in accordance with GB/T 19001—2000 standard.

In 1999, the State Food and Drug Administration (SFDA) began to enforce on the Good Manufacturing Practice (GMP) in radiopharmaceutical field to ensure the products safe and effective. By 2005, all enterprises for radiopharmaceuticals have been approved by SFDA in accordance with the requirements of GMP. From 2004 to 2007, the infrastructure and the working conditions in all units for radioisotope research, production and application throughout the country were upgraded with regard to the operating conditions and the surveillance means and intensified with regard to the management so as to ensure the safety of personnel and environment.

3.2 The progress in radioisotope preparing technology

Radioisotope preparing technology mainly includes the technology on the target preparation, the technology on reactor and cyclotron irradiation and the technology on chemical separation. The progress obtained in typical radioisotopes preparing technology in the recent years has clearly reflected the development of those technologies.

3.2.1 The reactor radioisotope preparing technology

1) ^{131}I (dry process). In the 1990s, the Nuclear Power Institute of China and the CIAE researched and established by itself successively the new ^{131}I production process in which the reactor-irradiated TeO_2 was dry-distillated to separate ^{131}I, thus replacing the wet ^{131}I extraction process formerly used and realizing a steady production and supply of ^{131}I. The ^{131}I production capacity at a single time reached hundred-curies level. In comparison with the wet process, the dry process is carried out in a sealed vacuum system and has such merits as higher ^{131}I yield, higher ^{131}I radioactive concentration and radiochemical purity, shorter production time, less radioactive waste produced, safer and more reliable, the ^{131}I produced being suitable to prepare ^{131}I -labeled mono-antibody and the ^{131}I capsule for use in therapy.

2) ^{125}I (batch loop method). In 2004, the CIAE researched and established by itself a new ^{125}I production process in which the enriched ^{124}Xe gas was irradiated by use of batch loop method, thus replacing the former ^{125}I production process with natural Xe gas target or low-enriched ^{124}Xe gas target being reactor-irradiated. In comparison with the former process, the new production process has such merits as simple, reliable and being able to use a reactor with low thermal neutron fluence rate for ^{125}I production. The ^{125}I produced by the new process contains less ^{126}I impurity, the quality of which reaches international advanced standard of the products of the same kind and meets the demand of ^{125}I seed source preparation and of radioimmuno-labeling.

3.2.2 Cyclotron radioisotope preparing technology

From 1995 to 1996, the CIAE and the Shanghai Amersham Kexin Pharmacy Company first established solid target system using the solid target station at 30 MeV cyclotron so as to research and produce radioisotopes such as ^{201}Tl, ^{67}Ga, ^{111}In and ^{57}Co, the solid target station being like the liquid target station and the gas target station in that they were all linked to the interface of the proton beam exported by the cyclotron. Before long, both units mentioned above further used the liquid target station to establish liquid target system, which is now mainly used to research and produce ^{18}F and ^{18}F-FDG. At the beginning of this century, many hospitals of our country introduced one after another from abroad PET and 10 MeV small-sized cyclotron complementary to it so as to research and produce some short-lived radioisotopes emitting positron including ^{11}C, ^{13}N, ^{15}O and ^{18}F and their pharmaceuticals.

1) ^{103}Pd solution. In recent years, the CIAE and the Shanghai Kexin Pharmacy Company carried out researches on ^{103}Pd preparing technology through the solid target system by use of proton cyclotron, of which the CIAE settled some key technical problems including Rh target preparation, dissolution and chemical separation, and completed ^{103}Pd development and production line, forming batch production capacity with about 3 curies per batch and the quality of ^{103}Pd meeting the requirements of ^{103}Pd seed source preparation.

2) ^{18}F and ^{18}F-FDG (liquid target and automatic synthesis). Along with the application of F-FDG in PET imaging diagnosis in our country expanding rapidly, some key techniques and the technical problems of generality including H_2O recovery and reuse during the course of ^{18}F preparation have been settled in our country, and the steady production of ^{18}F and ^{18}F-FDG and the supply on a batch basis have been basically realized.

3) ^{123}I (gas target). In 2007, the CIAE established a gas target system at the 30 MeV proton cyclotron and used the enriched ^{124}Xe gas target to produce ^{123}I. In comparison with the process using TeO_2 solid target to prepare ^{123}I, the process using the enriched ^{124}Xe gas target to prepare ^{123}I has such merits as less side reactions, higher ^{123}I yield and higher ^{123}I nuclear purity. When that system is completed, it will make a contribution to developing ^{123}I-radiopharmaceuticals and their application in our country.

3.2.3 Radionuclide generator

Radionuclide generator is such a sort of device that the shorter-lived daughter nuclide can be separated from the longer-lived parent nuclide. The research and application of radionuclide generator in our country have had a longer history. A vast amount of research on generators such as ^{99}Mo-^{99m}Tc, ^{113}Sn-^{113m}In, ^{90}Sr-^{90}Y, ^{188}W-^{188}Re and ^{68}Ge-^{68}Ga have been carried out, of which the development and application of both the fission ^{99}Mo-^{99m}Tc generator and the gel-type ^{99}Mo-^{99m}Tc generator are of most representative.

1) The fission ^{99}Mo and the ^{99}Mo-^{99m}Tc generator. The CIAE went through a development process from using reactor-irradiated low-enriched ^{235}U target in the early 1980s to using reactor-irradiated highly-enriched ^{235}U target in the early 1990s to research and produce the fission ^{99}Mo and the ^{99}Mo-^{99m}Tc generator. In 1995, that Institute settled a series of key technical problems with regard to fission ^{99}Mo extracting from irradiated highly-enriched ^{235}U target, and established a separation and purification process for 100 ~ 200 curies fission ^{99}Mo at a single production as well as three cyclic and hermetical production systems made of metal and an on-line measurement system. With regard to fission

$^{99}Mo-^{99m}Tc$ generator preparation, they settled a series of a series of key technical problem including cold column treatment of Al_2O_3 chromatographic column and the optimization of ^{99}Mo absorption, established a steady production process and quality assurance system for fission $^{99}Mo-^{99m}Tc$ generator free of bacteria and free of pyrogen, and completed the fission $^{99}Mo-^{99m}Tc$ generator production facilities with annual output of 5 000 generators, thus making the fission ^{99}Mo separation and purification process in our country and the high-activity fission $^{99}Mo-^{99m}Tc$ generator preparing technology raised to international advanced standard. This research project and its achievement played a key role for promoting the extended application of ^{99m}Tc SPECT pharmaceuticals in our country and for this reason it won the first prize of the National Science and Technology Progress Award.

2) Gel-type $^{99}Mo-^{99m}Tc$ generator. During the midterm of 1980s, the Nuclear Power Institute of China researched and produced by itself the gel-type $^{99}Mo-^{99m}Tc$ generator by MoO_3 irradiation on the high flux reactor, settled a series of key technical problems including the preparation of ^{99}Mo-Zr molybdate gel and the column loading technology, completed the gel-type $^{99}Mo-^{99m}Tc$ generator production line and realized the steady batch production. The IAEA has extended the technological achievements for application among the developing countries which possess the reactor with lower neutron fluence rate.

3.3 The progress in the preparation technology and application of the radiopharmaceuticals for use in modern nuclear medicine diagnosis and therapy

At present, there have been thirty-five kinds of radiopharmaceuticals in vivo in our country which were approved for production, among them ^{99m}Tc-radiopharmaceuticals (including ^{99}Tc) occupy sixteen kinds, ^{131}I-radiopharmaceuticals four kinds, ^{32}P and ^{113m}In-radiopharmaceuticals three kinds each, ^{67}Ga, ^{201}Tl, ^{89}Sr, ^{153}Sm, ^{198}Au, ^{14}C, ^{13}C, ^{51}Cr and ^{133}Xe-radiopharmaceuticals one kind each. The year 2005 edition "China Pharmacopoeia" collected seventeen kinds of radiopharmaceuticals containing seven kinds of radionuclides.

3.3.1 Radiopharmaceutical for use in diagnosis

At present, there have been over 800 hospitals throughout the country which set up nuclear medicine section to be engaged in the clinical application of radiopharmaceutical and possess about 60 PETs and PET/CTs as well as 400 sets of SPECT devices.

There have been over 3 000 medical treatment units throughout the country which are carrying out the work on radioimmunoassay.

1) SPECT radiopharmaceutical. ^{99m}Tc-pharmaceuticals are the SPECT pharmaceuticals which are most widely applied at home at present and can be used to carry out imaging diagnoses for nearly all organs of human body. By the midterm of 1990s, an integrated ^{99m}Tc-pharmaceutical research, production and supply system had been completed in our country. The ^{99m}Tc labeled pharmaceuticals (such as d, l-HM-PAO, ^{99m}Tc-ECD, ^{99m}Tc-MIBI and ^{99m}Tc-MDP) for use in disease imaging diagnoses including the heart and brain disease and the tumor were successively developed and produced. Thereafter, nearly 10 nuclear pharmacies for ^{99m}Tc-labeled pharmaceuticals were established in large and medium-sized cities one after another, giving a powerful impetus to the development of modern nuclear medicine in diagnostic application in our country. In the corresponding period, the cyclotron-produced pharmaceutical research, production and supply system including $^{201}TlCl$ and ^{67}Ga-citrate was completed in Beijing and Shanghai respectively.

It is worth pointing out that a research group led by Mr. Liu Boli in Beijing Normal University has obtained some important results in the research on Tc-chemistry and its structure-activity relationships and the radiopharmaceutical design. Among them, some patent results, such as ^{99m}Tc-MPBOA for cerebral perfusion imaging, $^{99m}Tc(CO)_3(MIBI)_3^+$ and $^{99m}TcN(PNP)(NOEt)$ for myocardial perfusion imaging agents, are of importance to develop new pharmaceuticals of self-innovation in our country.

In recent years, a fair number of research work has been carried out with regard to new peptide and mono-cloned antibody based pharmaceuticals, and some progress have been obtained.

2) PET pharmaceutical. The positron emission computed tomography (PET) has now become an optimum means to diagnose and to guide therapy of three kinds of diseases i. e. tumor, heart disease and brain disorders, which are seriously threatening the lives of mankind. The overwhelming majority of the ligands in PET pharmaceuticals are the endogenous metabolites of human-body or analogues. The PET pharmaceuticals prepared by labeling such ligands using radionuclides such as ^{11}C, ^{13}N and ^{15}O, which compose human body element can exactly reflect the biochemistry changes of organism under the physiological conditions and can make accurate quantitative analysis for biochemical process. The biological activities of ^{18}F labeled pharmaceuticals are also very similar to that of endogenous metabolite of human-body or analogue by means of replacing H atom in structure of molecules.

The CIAE developed successfully ^{18}F-FDG in 1997, which was first approved by SFDA at home and obtained the license in 2003. At present, following Atom-Hitech Co. Ltd. and Shanghai Kexin Pharmacy Company being able to produce and supply ^{18}F-FDG on a batch basis, some hospitals at home can also use their own 10 MeV cyclotron introduced from abroad to produce ^{18}F-FDG. Therefore, ^{18}F-FDG has now become the PET pharmaceutical which are most widely applied in our country.

In recent years, the research and the clinical application of positron pharmaceutical at home have had a great development. Besides ^{18}F-FDG, more than twenty kinds of PET pharmaceuticals, including ^{18}F-Tyrosine, ^{11}C-choline, ^{11}C-methionine, ^{18}F-FE-CIT and ^{11}C-CFT etc., have been successfully developed and applied to the clinical.

In the past, the PET pharmaceutical automatic synthesis equipment in our country depended on imports. In 2002, the ^{18}F-FDG automatic synthesizer was developed with success at home, whose various indices were close to the level of the imported product of the same kind. In the recent years, the automation modules for automatic synthesis of ^{11}C-methyl iodide, ^{11}C-choline and ^{11}C-methionine have also been successfully developed one after another at home.

3) RIA kit. In the late 1990s, the development in RIA technology and application in our country reached its summit and there were nearly 30 RIA kits production units throughout the country to produce and supply nearly one hundred kinds of RIA kits. Now there are over 3 000 medical units throughout the country to carry out RIA and approximate 25 millions patients accept the RIA test every year. Today, nearly 20 enterprises have passed through GMP authentication, making the RIA kit development and production more conform to the standard. In recent years, the development in RIA kit preparing technology and application in our country has been mainly reflected in the following three aspects. a. With regard to separation and purification method of labeled compounds, the column chromatography and paper chromatography etc. often used in the past are being gradually replaced by high-performance liquid chromatography (HPLC). At present, a number of research and production units have adopted the HPLC method to separate and purify labeled compound, thus making the purity and activity of labeled compound further raised and the product quality guaranteed. b. The separation method of bound fraction from the free ^{125}I-labeled compounds is developing from liquid phase separation (e. g. second antibody PEG separation method) to solid phase separation (e. g. coated tube and magnetic particle method), thus making separation method simpler, faster and more convenient. c. The application of RIA technology has not been confined only to medical research and clinical diagnosis, but has been expanded to many fields such as agriculture, food safety, environment and drug addiction.

4) ^{13}C- and ^{14}C-urea (carbamide) capsule breath test kits. As early as 1998, US FDA approved ^{13}C- and ^{14}C-urea capsule breath test kits to be put into market, which were widely used to detect helicobacter pylori infection for patients. Around the year 2004, the Shenzhen Haidewei Company under the China Isotope Cooperation and the Atom-Hitech Company etc. were respectively approved to produce the ^{14}C-urea capsule breath test kit and the ^{13}C-urea capsule breath test kit and to spread their application in the domestic hospitals clinic examination successively, with the development very fast.

3.3.2 Radioactive therapy pharmaceutical

1) ^{153}Sm-EDMTP injection. In the last century, the 1980s to the early 1990s, the CIAE and the China Academy of Engineering Physics etc. followed closely international development trend of radioactive therapy pharmaceutical and first selected ^{153}Sm-EDMTP bone tumor therapy agent as a research subject. By the mid-term of 1990s, both units mentioned above made some progress on that subject respectively. During 1996 to 2000, the CIAE developed with success ^{153}Sm-EDMTP bone tumor therapy agent using reactor to irradiate the enriched ^{152}Sm target and completed various research of clinical test in the first and the second phases. In 2003, those two units acquired new pharmaceutical approval number and the production license respectively, thus the ^{153}Sm-EDMTP became the first new pharmaceutical for use for radioactive therapy in our country which passed through the new pharmaceutical examination and approval by the State according to the new pharmaceutical examination and approval procedure and which possessed the independent intellectual property right, and with which the life quality of the patients in advanced stage of bone metastases has been greatly improved.

2) $^{89}SrCl_2$ injection. In the late 1990s, the Shanghai Kexin Pharmacy Company sub-packaged the imported $^{89}SrCl_2$ from abroad and made it into $^{89}SrCl_2$ injection so as to supply the domestic hospitals for the clinical application.

$^{89}SrCl_2$ injection and ^{153}Sm-EDMTP injection have been become in recent years the two radioactive therapy pharmaceuticals which have been most applied in bone tumor clinical therapy in our country.

3) ^{99}Tc-MDP (Yunke). ^{99}Tc-MDP (Yunke) was a kind of pharmaceutical for use in rheumatoid arthritis therapy which was researched and developed successfully by the Nuclear Power Institute of China in 1990s and possessed the independent intellectual property right, and won "National Key New Product Certificate". This pharmaceutical has such roles as therapy, immunity adjusting and restraining inflammatory medium for autoimmune disorder, tumor transfer to bone and other related bone diseases.

4) ^{131}I-ChTNT injection and ^{131}I-Meituxie monoantibody injection. Now it has been in the 21^{st} and the monoclonal-antibody preparing technology and the nuclide labeling technique have been broken through, which created favorable conditions for making material progress in clinical application of treating difficult and complicated diseases including tumor by use of radioimmuno-therapy pharmaceutical in our country.

The ^{131}I-Meituxie mono-antibody injection for treating liver cancer has been developed by The Fourth Military Medical University and the Chengdu Huashen Group. The ^{131}I-tumor cell nucleus human/mouse chimera mono-antibody injection (^{131}I-ChTNT injection) for treating lung cancer has been developed by Shanghai Bo-En Bio-technology Company. Both of them have acquired new pharmaceutical approval number and the pharmaceutical production license in 2006 and in 2007 respectively.

The development and production of both new pharmaceuticals mentioned above and clinic application marks the radioimmuno-therapy pharmaceutical preparing technology have reached the world advanced level.

3.3.3 After-loading implanted radiotherapy source

The radiotherapy pattern can be divided into two types, i. e. internal irradiation and external irradiation. The external irradiation therapy usually uses X-ray therapy unit, ^{60}Co therapy machine and accelerator etc., while internal irradiation therapy uses after-loading sources (such as ^{192}Ir or ^{252}Cf etc. after-loading sources) or radioactive seed sources (such as ^{198}Au, ^{125}I and ^{103}Pd seed sources) for implanted therapy.

In recent years, the after-loading implanted radiotherapy source preparing technology and their application in our country have made great progress.

1) ^{192}Ir after-loading therapy source. ^{192}Ir after-loading therapy machine is a kind of brachy after-loading therapy equipment with high dose rate which was put into application internationally in 1980s. It makes the application of after-loading technology expanded from traditional gynecology tumor therapy to cancer therapy fields such as nose and pharynx, esophagus, rectum, colon and bladder cancer.

In the early 1990s, the research work was started in our country to exploit ^{192}Ir after-loading therapy source and to develop the preparation technology of the sealed radioactive source with a small-size. By the mid-term of 1990s, the CIAE and the Nuclear Power Institute of China had successively developed with success ^{192}Ir after-loading therapy source with small-size and high activity which was complementary to ^{192}Ir after-loading therapy machine with the preparation technology coming up to international advanced level, and completed the integrated production and supply system at home, thus laying the foundation for developing ^{192}Ir after-loading therapy in our country.

2) ^{60}Co source for use in γ-knife and ^{252}Cf source for use in neutron knife. China is the biggest production and supply country of ^{60}Co γ-knife equipment in the world. In the midterm of 1990s, the Nuclear Power Institute of China used high flux reactor to develop and produce ^{60}Co powerful radiation source with high specific activity which was complementary to the domestic γ-knife equipment. In order to meet the demand for γ-knife equipment at home, the Nuclear Power Institute of China and Beijing Shuangyuan Company imported respectively from abroad ^{60}Co radiation source with high specific activity, through which a system covering supply, installation, rearrangement and service of source complementary to domestic γ-knife equipment was completed.

In the late 1990s, the Shenzhen Lingdum Company developed with success ^{252}Cf neutron after-loading therapy system, which was applied in over 10 hospitals at home. Beijing Shangyuan Company used the imported ^{252}Cf from Russia to prepare after-loading therapy source with a small size which was complementary to the domestic ^{252}Cf neutron after-loading therapy system. It has achieved obvious curative effect in clinical therapy including cervical cancer and esophagus cancer.

3) $^{90}Sr/^{90}Y$ prostate gland hyperplasia therapy source. $^{90}Sr/^{90}Y$ prostate gland hyperplasia therapy instrument was a patent product with originality which was developed with success by the CIAE in 1996. The core part of that therapy instrument was $^{90}Sr/^{90}Y$ prostate gland hyperplasia therapy source. Both the determination of the source preparing scheme and the choice of therapy application embodied the creativeness or the originality, which has not been reported so far. The clinical observation to thousands of cases by a few dozens of hospitals including the Beijing Hospital and the Beijing 301 Hospital showed that that kind of therapy instrument had achieved satisfactory curative effect. For that reason, that therapy instrument as one of med-

ical apparatuses and instruments obtained new product approval number and product production license issued by the State, and has become another kind of new type apparatus which can be chosen by the patients after micro-wave, radiofrequency and laser prostate gland hyperplasia therapy instrument were put into use. It possesses a good prospect of application and extension.

4) ^{125}I seed source. Tissue space implanted therapy pattern using radioactive seed source has been a kind of new type therapy technology which is developing at home and abroad in recent years. The most commonly used radioactive seed sources are ^{125}I seed source and ^{103}Pd seed source.

Since 2000, the Shanghai Xinke Pharmacy Company, the Atom-Hitech Company and the Ningbo Jun'an Pharmacy Company have successively developed with success ^{125}I seed source and acquired the approval number of that product and production license respectively, realizing production and supply on a batch basis. All three units mentioned above settled a series of key techniques and technical problem of generality including source core preparation of ^{125}I seed source, seal, apparent activity and dose distribution measurement. Among them, as a result of recent years' research work, the Atom-Hitech Company chose laser-welding machine and electron beam welding machine for ^{125}I seed source seal, realized the process automation including source entering, welding, sealing, leak-testing and measuring, and completed ^{125}I sealed seed source production line which accorded with the GMP requirements and possessed the production capacity daily of 1 000 to 1 500 grains, the product quality coming up to international advanced standard of the product of the same kind.

As a result of market spread for several years, there have been nearly one hundred of hospitals at home which are using ^{125}I seed source at present, with the annual demand quantity of about 200 thousand grains. With the domestic seed source dosimetry parameters further perfect and the seed source therapy system and the related complementary equipment continuously improved, the application prospect of ^{125}I sealed seed source will become much broader.

5) ^{103}Pd seed source. ^{103}Pd seed source is a kind of sealed seed source made of ^{103}Pd produced by means of cyclotron. ^{103}Pd seed source has been widely applied abroad to the radioactive seed source implanted therapy, but it's still a blank in China.

In 2006, the Atom-Hitech Company used ^{103}Pd produced by means of cyclotron to accomplish the related research and experiment work including ^{103}Pd seed source preparing technology as well as the animal test and clinical verification of the trial-product. At present, all the related matters such as the product approval number and production license are being carried through.

3.4 The progress in the radioactive source for industrial use preparing technology and application

In 1980s, our country researched and established the source core preparing technologies including powder metallurgy, enamel and ceramics, electroplate and gas-filling methods, the source sealing technologies and the source examining and testing technologies according to the related standards of sealed radioactive sources and the practical needs in application.

In recent years, the development in radioactive source preparing technologies of our country has been mainly reflected in the following three aspects. a. The source core preparing technologies including the choice of radioisotope used in sources and its formula as well as source core preparing technologies are developing towards such a direction that they are suited to raise the utilization ratio of radioactive material used in sources, emission rate, stability, reliability and safety. b. The sealing technologies of sources are developing towards such a direction that they are suited to seal different source shell materials or the covering layer of source core so as to raise the safety, stability and reliability of sources under the environment in which the sources are used. c. The examining and testing technologies of sources are developing towards such a direction that they can meet all kinds of requirements for examining, testing and analysis measurement fixed in the standards.

In recent years, the remarkable progress has been made with regard to the preparation technologies and application of some typical radioactive sources for industrial uses in our country.

3.4.1 ^{241}Am smoke detector source

During the early 1980s to the mid-term of 1990s, the CIAE, the China Academy of Engineering Physics and Jiuquan Atomic Energy Complex carried out a lot of research work on ^{241}Am smoke detector source preparing technology by use of powder metallurgy method. They established successively the preparation technique and production lines for ^{241}Am smoke detector source with the covering layer of gold or of gold-palladium, and the quality of the products they produced was able to meet the requirements of the domestic producer which produced the fire-alarm system of ionization smoke detector, coming up to international advanced level of the same kinds of products at that time. The technology achievement made by the CIAE with regard to ^{241}Am smoke detector source with the covering layer of gold won a third prize of the National Science and Technology Progress Awards. Under the impetus of the level of the domestic ^{241}Am smoke detector source preparing technology being continuously heightened, the domestic fire-alarm system industry developed rapidly to become the first big industry in the field of nuclear control system in our country at that time. In the late 1990s, the Amersham Company of England became a main production and supply enterprises of ^{241}Am smoke detector source throughout the world. In the recent years, that Company has transferred the ^{241}Am smoke detector source production into the Atom-Hitech Company in China, the output of its production and supply having accounted for three-fourths of the world market.

3.4.2 ^{238}Pu static electric eliminator

In 2003, the domestic electron chips industry made new urgent demands for ^{238}Pu static electric eliminator in order to settle the static electric elimination problem. The Atom-Hitech Company developed and produced the belt shaped ^{238}Pu alpha source with the covering layer of gold-palladium using the powder metallurgy method, and made successfully the ion wind-type ^{238}Pu stastic electric eliminator by assembly, which was applied to electron chips industry with a good effect. In comparison with the preparation technologies of ^{238}Pu source for use in static electric eliminator which were formerly used in our country, the ^{238}Pu content in ^{238}Pu source for use in ion wind-type ^{238}Pu static electric eliminator was greatly decreased, thus the safety in both operation and application being obviously raised. It has been the most important progress in the preparation technologies of ^{238}Pu source for use in static electric eliminator.

3.4.3 Neutron source for use in logging in oilfield

Neutron source is absolutely necessary to the application of neutron logging in oilfield and the most commonly used source is ^{241}Am-Be neutron source. During the mid-term of 1970s to the mid-term of 1980s, the CIAE carried out a lot of research work around preparing ^{241}Am-Be neutron logging source with a method of powder press (by use of powder pressing method). At the beginning, the dry mixed technique was adopted with the neutron yield of ^{241}Am source being merely 1.6×10^6 Ci (1 Ci $= 3.7 \times 10^{10}$ Bq), while the neutron yield of the product with the same specifications abroad came up to 2×10^6 Ci ^{241}Am. In 1986, the CIAE adopted the wet mixed technique with the neutron yield coming up to the advanced level of the same kinds of product abroad. That research result won a third prize of the National Science and Technology Progress Awards. Soon afterwards, the CIAE completed the production facilities for ^{241}Am-Be neutron source for use in logging in oilfield, meeting the needs of logging in the domestic oilfield, with a small amount of the ^{241}Am-Be neutron sources exported.

In 2006, the Atom-Hitech Company also developed and produced ^{238}Pu-Be neutron source for logging, whose structure design, wrapping shell materials and the sealing technology are more suited to the requirements for safety performance of source in logging in oilfield.

3.4.4 Neutron source for use in reactor startup of nuclear power plant

In 1991, the ^{210}Po-Be neutron source rod developed and produced by the CIAE was used for reactor startup of the first nuclear power plant of our country i.e. Qinshan I Stage 300 MW Nuclear Power Plant. Afterwards, the domestic ^{210}Po production was stopped. The CIAE imported ^{252}Cf raw materials through cooperation with Russia and developed successfully ^{252}Cf neutron source rod for reactor startup in 1998, which was used to startup the reactor of Chashma Nuclear Power Plant in Pakistan which was constructed with the help of China.

The achievement in neutron source preparing technology and the progress in application mentioned above fully reflect that our country has mastered neutron source preparing technology involving diversified radioisotopes, and the products developed and produced can meet the requirements of many-sided application and come up to advanced level or international level of the same kind of products.

3.4.5 Thickness gauging sources such as ^{147}Pm, ^{85}Kr, and ^{90}Sr/^{90}Y for use in thickness gauge and thickness gauging control system

Thickness gauging source is a kind of radioactive source with which radioisotope thickness gauge and thickness gauging control system can obtain thickness (density) parameters. The thickness gauging sources in common use at home at present are ^{147}Pm, ^{85}Kr, ^{90}Sr/^{90}Y, ^{55}Fe, ^{241}Am and ^{137}Cs sources etc., which were developed and produced mainly by use of such preparation technology as powder metallurgy, gas-filling, enamel and ceramics as well as electroplate and so on.

As early as 1980s, the CIAE researched and developed the preparation techniques for thickness gauging sources in common use mentioned above and was able to supply some products.

In recent years, the CIAE has established a new ^{147}Pm source preparing technique through developing ^{147}Pm thickness gauging source with high activity. An optimum preparation program has been found relating the appropriate formula, the shaping and the rolling of ^{147}Pm source core active lump with high activity. That preparation program not only settled the problem of ^{147}Pm β-ray self-absorption and improved the utilization rate of radioactive raw and processed materials, but also a batch of ^{147}Pm thickness gauging source with high activity have been produce which are suited to radioactive thickness gauging or thickness gauging control system installed in the production lines imported from abroad.

3.4.6 γ-radiation source for use in γ-flaw detection, CT and container inspection system imaging, ^{192}Ir, ^{75}Se and ^{60}Co, etc.

γ-sources such as ^{192}Ir, ^{75}Se and ^{60}Co source are often used for γ inspection (non-destructive testing). Since 1990s, both the Nuclear Power Institute of China and the CIAE have developed and produced non-destructive testing source for the domestic non-destructive detection applications. In addition, the Nuclear Power Institute of China also uses its own high flux reactor to develop and produce ^{60}Co source for the domestic non-destructive detection applications.

Now the Nuclear Power Institute of China is using its high flux reactor to irradiate the enriched ^{74}Se with the aim of developing a new ^{75}Se non-destructive detection source.

^{75}Se non-destructive testing source is a kind of source for industrial use which has been newly developed internationally in recent years. With ^{75}Se flaw detection source, one can see through the welding seam of small diameter tube and of vessel and pipeline with the diameter under 40 mm and the quality of flaw detection by use of ^{75}Se is superior to that one by use of ^{192}Ir, which is a breakthrough in non-destructive detection technology. At present, the domestic ^{75}Se non-destructive detection source depends on the imports.

In the late 1990s, the industrial CT and the container inspection system imaging technology started to develop gradually in our country. Generally the ^{60}Co radiation source with small size and high activity was adopted. At present, such ^{60}Co radiation sources with small size and high activity which Tsinghua University and the CIAE used for developing and producing ^{60}Co container inspection system and industrial CT basically depend on the imports.

3.5 The progress in radioisotope tracer technology and application

The radiotracer technology is such a technology that for a specific designated system or some group of the system, its behavior or characteristic information can be acquired by use of radiotracers. The radiotracer technology possesses such merits as high sensitivity, non-destructive and being able to make real-time testing. That technology has been widely applied in many fields such as oilfield, environment, hydrology and geology, with major progress won.

3.5.1 Radiotraces in the oilfield

The water flooding development is a main form of oilfield exploitation in our country. The radiotracer plays a very important role in the course of oilfield exploitation.

1) Water injection profile radiotracer logging. In the early 1980s, the CIAE collaborated with the Daqing oilfield to research and develop with success ^{131}Ba-microsphere tracer and completed the ^{131}Ba-microsphere production facilities of annual output of 5 t at the end of 1980s.

The technology achievement the CIAE obtained in such aspects as selecting the nuclide for use in microsphere, adsorption of tracer and the coat made the preparation technology of the tracer for oilfield logging in our country raised to international advanced level, which aroused high attention of the same profession abroad. Because ^{131}Ba-microsphere can be fully dissolved after staying for about 30 days under a well, it possesses such merits as it being unable to form a block to oil layer, nor causing oil pipe and packer under a well obviously polluted, which fully embodied the advanced nature and unique superiority of this preparation technology. The application of ^{131}Ba-microsphere tracer promoted the development of water absorption profile logging by use of radioisotope tracing and has been rapidly extended to all oilfields throughout the country. In recent over 10 years, the annual workload in water absorption profile logging by use of ^{131}Ba-microsphere tracing has all exceeded 10 000 well-time, with very remarkable effects obtained.

2) Inter-well tracer test by radioisotopes. At present, the secondary and the tertiary oil recovery need to use some injection fluids according to the different oil reservoir types and exploitation phases. The injection fluids adopted are: water, gas (natural gas and carbon dioxide), water steam as well as the aqueous solution containing polymer (polyacrylamide) or micro-organism. The inter-well tracers used are mainly divided into three categories i.e. tracers for water drive, gas drive and steam drive. Of them the tritiated water is the most ideal aqueous phase tracer and the steam tracer while the tritiated alkylation-hydrocarbon and the carbon dioxide labeled with ^{14}C are the best gas tracers.

In 1988, the Daqing oilfield collaborated with the CIAE to start the application of tritiated water to inter-well tracer test, with a good effect obtained. Then they launched the research work on the application of tritiated methane in gas-drive tracing. At the same period, the Dagang oilfield also launched the inter-well tracing test by use of tritium oxide with the support of the IAEA technical cooperation item. From 1993 to 1997, the three bigger oilfields in our country i. e. the Shengli, the Daqing and the Liaohe oilfields collaborated successively with the CIAE to launch the research on inter-well test by use of radioisotope. For instance, the Shengli oilfield launched the research on gamma radiotracer water drive inter-well tracer test and tritiated water steam drive inter-well tracing test respectively using successively radiotracers such as ^{60}Co-potassium cyanide, ^{125}I-NaI, ^{51}Cr-EDTA complex and tritiated water. The Liaohe oilfield in collaboration with CIAE launched the research on activable tracing inter-well test using the EDTA complex of rare earth element as water drive tracer, and then completed the research on inter-well surplus oil saturation degree test using distributable tracer i. e. tritiated n-butyl alcohol. The achievements in the research on inter-well tracing tests mentioned above possessed great significance to guide the tertiary extraction in oilfield and monitor the surplus oil saturation degree of oil-pool. Based on those achievements, the CIAE collaborated with the China National Petroleum and Natural Gas Group Cooperation and the Dagang oilfield during 1999 to 2001 to jointly complete the IAEA technical cooperation item "To monitor surplus oil saturation degree of water injection oil-pool using inter-well radio-tracing technology".

In 2003, the Petroleum University (Huadong) collaborated with the CIAE to complete the development of computer software on inter-well tracing comprehensive explanation. In 2002, the CIAE brought forward "Slight Disturbing Inter-well Tracing Test Method" and applied for China invention patent for that method.

At present, the CIAE has developed with success three big categories of radioisotope tracer to be used respectively for water drive, gas drive and steam drive inter-well tracing test and inter-well surplus oil saturation degree test; developed a series of tracer analysis method; established a special laboratory to be used for oilfield inter-well tracing research and service including instruments, equipment and oil-pool simulation software; gradually formed a technical service system for inter-well radioisotope tracing test. The inter-well tracing technical service has been extended to various big oilfields throughout the country and will be gradually moved towards international market.

It's worth noting that the inter-well tracing test for tertiary oil extraction by use of the polymer-injection hasn't been still launched at home and abroad at present. Maybe this is one of directions worthy of note in radioisotope inter-well tracing test in the days to come.

3.5.2 The application of radiotracer in the research on environment and hydrogeology

Radioisotope tracing technology can play an important role in the research on environment and hydrogeology. For instance, the CIAE collaborated with ANSTO of Australia in 1999 to launch the radioisotope tracing experiment for the project of draining off sewage of small river bends into sea in Hong Kong. The aim of the experiment was to evaluate the project option of draining off sewage into sea so as to provide scientific basis for the optimized design of that option. Two kinds of tracers i. e. ^{198}Au and tritium oxide were used in that tracing experiments and two experiments were carried out at the flood-tide and at ebb-tide respectively. The data of tracing experiment perfected effectively the computer model of draining off sewage of small river bends, thus providing the basis for finally fixing the sewage draining outlet and for the design of the sewage draining velocity.

In addition, the Nanjing Hydraulic Research Institute etc., collaborated with the CIAE in 1991 and in 1999 with the support of the IAEA to launch successively the research on sediment movement and transfer at the Yangtze River outlet and Qingdao Port using ^{46}Sc and ^{192}Ir tracing sands respectively, and that research results were used to guide dredge engineering of waterway and harbor, with satisfactory effects achieved.

4 Look forward to the future

The radioisotope technology in our country has undergone a development course over 50 years and has possessed a considerable foundation, scale and technological level at present.

The application of radioisotope technology in our country has infiltrated into various sphere such as industry, agriculture, medicine and scientific research. Among them, the application in medicine is the most active while the application in industry and the other spheres are gradually developing in-depth.

In recent years, the construction for nuclear science and technology base and nuclear industry system of our country has entered into a new developing period, which will lay down a new foundation for the development of radioisotope technology in our country.

Around the 2010, our country will have two research reactors, one fast reactor and the installation for producing ^{60}Co radiation sources by use of the reactor in Qinshan III Stage Nuclear Power Plant to be put into operation, which will provide powerful sustainable conditions for the further development of radioisotope technology and application in our country after "the 12th Five-Year Plan".

It should be seen that along with the rapid development of economy, society, science and technology in our country and with comprehensive national strength continuously enhanced, to ensure national security and people's health, to construct a innovational country and to build a harmonious society have become the established state policies for the future development of our country. It will certainly put forward the new requirements for the future development of radioisotope technology and application in our country and presage a new development prospects.

Before all others, the emphasis will be put on building several centers for research and production of radioisotope and its product which will be complementary to reactor and cyclotron and will be in line with international standards on the basis of reactors and cyclotrons in Beijing, Shanghai and Sichuan province, and thus forming a product supplying system which will cover the whole country.

Next, the research on radioisotope preparing technology and application technology in our country will be gradually marching towards socialization; a rationalized pattern will be gradually formed with some superior enterprises or units having powerful comprehensive technology strength as mainstay.

It can be expected that the developing prospects of radioisotope technology and application in China will be becoming much broader in the coming 10 ~ 20 years.

The preparation technology for radioisotopes with high nuclear purity, high specific-activity and high radioactive concentration (the shorter form is "three-high" radioisotope preparing technology) in our country will have an important development.

For that reason, it will be the most effective channel to enhance the reactor and cyclotron utilization level that various enriched stable isotopes will be rationally chosen as target through studying in-depth nuclear reactions around reactor and cyclotron irradiation.

The continuous development of the "three-high" radioisotope preparing technology will promote the more effective combination of radioisotope technology with modern life-science, bio-technology and imaging technology, with which the research on molecular probe, gene probe, proteomics, genomics and on the mechanism of mankind disease will also continuously make significant progress, and which predict at the same time an major breakthrough will emerge in the modern radio-diagnosis and therapy, biological medicine and its application in our country.

The preparation technology will be raised to a new development level with regard to the ^{3}H and ^{14}C labeled compounds which are used for verifying the research and development process of innovative pharmaceutical and to ^{32}P and ^{35}S labeled nucleotides with high-specific activity which are used for the research on life-science.

After the year 2010, ^{60}Co source irradiation station, γ-knife therapy device as well as the preparation technology for strong radiation sources such as ^{192}Ir, ^{75}Se and ^{60}Co which are used for industrial CT and container inspection system imaging will acquire a great development, thus bring about a new development prospects for radiation technology being more extensively applied.

New type of tracer and the radiotracer technology will play more and more important role in the energy source development and the environment control and treatment.

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