

# ACCELERATOR-BASED MEGA-SCIENCE PROJECTS IN CHINA AND THEIR IMPACT ON ECONOMY

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## Abstract

Along with the rapid development of national economy in China, a number of accelerator based mega-science projects were constructed, such as the Beijing Electron-Positron Colliders (BEPC) and its major upgrade project (BEPCII), the Hefei Light Source (HLS), the Heavy Ion Research Facility in Lanzhou (HIRFL) and its Cooling Storage Rings (HIEFL-CSR), the Shanghai Synchrotron Radiation Facility (SSRF) and the Dragon-I induction linac. The Beijing Radioactive Ion Facility (BRIF) and the China Spallation Neutron Source (CSNS) are under construction. In this paper, China's accelerator projects are briefly reviewed and applications of accelerators are reported. The paper emphasizes spinoff of the accelerator technology developed during R&D and construction of the projects. Collaboration between academia and industry on the projects are described. With some examples, the benefits experienced in the laboratory-industry collaboration and approach of its economic impact are illustrated.

The collider operated for both high energy physics experiments in charm and  $\tau$  range and synchrotron radiation application at 2.2 GeV for 16 years before its major upgrades, namely BEPCII, was started in 2004. As a natural extension of BEPC, the BEPCII project started its construction in the beginning of 2004. BEPCII is a double-ring collider. The design luminosity of BEPCII is  $1 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$  at 1.89 GeV. Some key technologies were developed to achieve the goal of the project. The project was completed in 2009 and operation started therewith. The peak luminosity reached  $6.5 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$  at 1.89 GeV. Performance of BEPCII as a synchrotron radiation source is also improved with beam current of 250mA at 2.5 GeV and full energy injection from the linac [2].

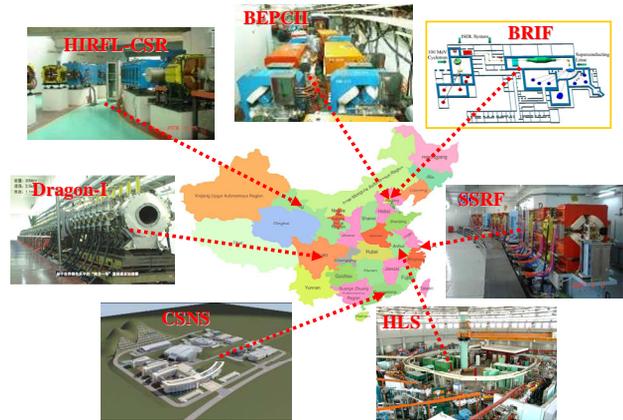


Figure 1: Geographical distribution of accelerator facilities in China

## ACCELERATOR BASED MEGA-SCIENCE PROJECTS IN CHINA

A number of accelerator based mega-science projects were or are being constructed in China after 1980's. Table 1 lists their basic facts, and Figure 1 is a map showing geographical distribution of the accelerator facilities in China.

Table 1: Basic facts of accelerator projects in China

Machine	Host Lab	Constr. Period	Cost* (MUSD)
BEPC	IHEP	84-88	34.3
BEPCII	IHEP	04-09	91.4
HLS-I	NSRL	84-89	11.4
HLS-II	NSRL	99-04	16.9
HIRFL	IMP	84-89	32.9
HIRFL-CSR	IMP	00-08	49.1
Dragon-1	CAEP	98-03	42.9
SSRF	SINAP	05-09	187.7
BRIF	CIAE	11-	55.7
CSNS	IHEP	11-	238.6

\* Assuming 1USD=7 RMB

As the first high energy accelerator in China, the Beijing Electron-Positron Colliders (BEPC) started construction in Oct. 1984 and completed in Oct. 1988 in the Institute of High Energy Physics (IHEP). BEPC consists of a 1.55 GeV linac injector, a 1-2.5 GeV storage ring, the Beijing Spectrometer and the Beijing Synchrotron Radiation Facility [1]. The maximum luminosity of BEPC reached  $1 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$  at 1.89 GeV.

Hefei Light Source is the first dedicated synchrotron radiation source in China. HLS consists of a 200 MeV linac as injector, an 800 MeV storage ring as well as beamlines and experimental stations, operating in the VUV and soft X-ray range [3]. From 1999 to 2004, the National Synchrotron Radiation Laboratory (NSRL) carried out HLS Phase-II project, in which a few subsystems in HLS were upgraded and 8 new beamlines were constructed. After completion of the project, operation reliability and performance of HLS is improved considerably. The beam current is above 250 mA, beam lifetime is longer than 8 hours, orbit stability met the requirement of users, and efficiency of the machine operation has risen greatly. The capability of HLS to serve synchrotron radiation users has enhanced significantly [4].

Heavy Ion Research Facility in Lanzhou is one of China's three large accelerator projects in 1980's. HIRFL consists of the Sector Focus Cyclotron (SFC,  $k=69$ ) as injector, the Separated Sector Cyclotron (SSC,  $k=450$ ) as main cyclotron and experimental facilities. HIRFL can provide heavy ions of many species from  $\text{C}^{4+}$  to  $\text{U}^{90+}$  with beam energy of 100 MeV/u for  $\text{C}^{4+}$  and 10 MeV/u for

$U^{90+}$  respectively [5]. CSR is a new ion cooler-storage-ring system in the Institute of Modern Physics (IMP), which consists of a main ring (CSRm) and an experimental ring (CSRe) with SFC and SSC as injectors. The construction of CSR was completed in 2005. It was commissioned in the following two years. In 2008 the main purposes of CSR was focused on the primary  $Kr^{28+}$  beam with kinetic energy up to 500MeV/u for precise mass spectroscopy at CSRe at isochronous mode. The nuclear physics experiments have been carried out with the bright cooled ion beams. The cancer therapy phase-II in IMP with 80-430MeV/u carbon beam from CSRm was tested with tumours in the heads were treated successfully [6].

The Shanghai Synchrotron Radiation Facility (SSRF), located in the Shanghai Institute of Applied Physics (SINAP) at Zhang-Jiang Hi-Tech Park in Shanghai, is a third generation light source. SSRF consists of a 150MeV electron linac, a full energy booster, a 3.5GeV storage ring with circumference of 432m and seven beamlines and experimental stations based on the storage ring. The SSRF construction started in December 2004 and completed in May 2009. The user experiments started subsequently with 7 beamlines. The typical operating beam current is from 210mA to 140mA, the beam lifetime is around 30 hours. Top-up operation mode has been successfully tested to improve the performance. As the upgrade of the facility, about 30 more beamlines and experimental stations will be constructed in SSRF from 2011 to 2016 [7].

Following to completion of China's first induction linac LIAXF of 12MeV, the Dragon-I induction linac was built at Institute of Fluid Physics, China Academy of Engineering Physics (CAEP). Dragon-I consists of an injector of 12 induction cavities, an accelerating section of 72 cavities and the experimental facility. It can produce 2.5~3kA high current electron beams with energy of 20MeV and pulse width of 70ns. The spot size of about 1mm diameter has been achieved with beam current greater than 2.5kA. Linear induction accelerators are widely used in many research areas such as radiography, free electron laser, high power microwave, heavy ion fusion and so on [8].

Many activities in accelerator research and development have been carried out in the China Institute of Atomic Energy (CIAE). The Beijing Radioactive Ion-beam Facility (BRIF), namely the tandem upgrading project, is being constructed. BRIF consists of a 100 MeV compact cyclotron, CYCIAE-100, as the driving accelerator, an existing  $2 \times 13$  MeV tandem and a superconducting linac of QWR structure as a booster accelerator. Both radioactive and stable nuclei in the energy range from 14.5 MeV/A ( $^{12}C$ ) to 4.9 MeV/A ( $^{133}Cs$ ) can be obtained with high resolution and variable energies. BRIF will be an advanced and competitive facility for searching new nuclides and studying nuclear structure physics, nuclear astrophysics, nuclear reaction mechanism, atomic physics, material science, life science as well as other applications of nuclear physics [9].

China Spallation Neutron Source (CSNS) are under construction in Dongguan, Guangdong Province. CSNS mainly consists of an H<sup>-</sup> linac, a rapid cycling proton synchrotron, a target station and spectrometers for experiments. CSNS is designed to accelerate proton beams to 1.6GeV at 25 Hz repetition rate, striking a solid metal target to produce spallation neutrons. CSNS is designed to deliver beams of 100 kW with the upgrade capability up to 500 kW. A series of R&D have been conducted since 2006, including an H<sup>-</sup> ion source, a DTL tank, an RF transmitter for the linac, injection/ extraction magnets and their power supplies, dipole and quadrupole magnets and their power supplies, a ferrite-loaded RF prototype cavity, ceramic vacuum chambers, as well as control and beam diagnostic devices [10].

### IMPACT OF THE ACCELERATOR PROJECTS ON ECONOMY

Particle accelerators are integrated instruments with many hi-tech components. To reach the scientific goal of a mega-science project, the builders of the project must develop advanced technology. In this way, accelerator projects promote the progress of science and technology and bring about a positive impact on economy.

#### *To Promote Accelerator Related Technology*

Particle accelerators involve a great deal of advanced technologies, such as high power microwave & radio frequency, accurate magnets and their power supplies, ultra-high vacuum, beam diagnosis, computer control, superconduction, cryogenics, accurate mechanics, survey & alignment and others. The construction of accelerator projects in China can be traced to 1980's, when only a minor knowledge was mastered. Thanks to many labs in the world, we got a good start with BEPC and other early machines. Along with the development of national economy in China, more accelerator projects have been designed and constructed; and the corresponding technology has made progress by leaps and bounds. As examples, Figure 2 illustrates some advanced devices constructed and applied in China's accelerators.



Figure 2: Examples of technology development in construction of accelerator projects

Advanced ion sources, electron guns, positron sources, accelerating structures and other microwave components, klystrons, various magnets, power converters, RF cavities, insertion devices, vacuum devices, beam monitors, electronics, computer control, injection components, superconducting devices, cryogenics have been developed in China's accelerators. Some of them were provided to accelerator labs abroad. All of that happened significantly upgrade the industrial technology.

### *To promote technology upgrades of enterprises*

Construction of accelerator projects is joint efforts of both institutions and industry. Usually, the institutes carry out design and R&D for key technologies of the projects, while factories go along for mass production. Typically, some hundreds of enterprises take part in a project for manufacturing its devices. The manufactures by a long way upgrade their technical capability during the project construction.

The Weifang Huaguang Electronic Group Co. Ltd. of Shandong Province grew out of the Weifang Radio Factory. It was a small company with about 20 technical staff and 200 workers producing pocket radio sets when it took on manufacture of the BEPC electronics system. The factory produced more than 200 sets of high quality electronics devices for BEPC. As a result, the first CAMAC and NIM series products with international standard in China were then developed by the factory. Undergoing 20-years development, the Huaguang Electronic Group has become one of the top 100 electronics enterprises in China with more than 20 branch companies and 7000 employees involving electronics, computes, computer-to-plate system, SPC exchange systems, mobile communication and transmission equipment, and other fields.

The Tianshui Electric Drive Research Institute Co. Ltd. (TEDRI) is one of R&D and production bases in electric drives and automation in China. Since 1999, TEDRI have produced high-precision power converters for HIRFL-CSR, BEPCII, HLS and CSNS. The company closely collaborated with the institutions in main circuit design, technical topology structure, digital control board etc. And this has promoted the technology and product upgrade of the company. By applying the technology developed in accelerator power converters such as digital control, IGBT and others, new type of transducers were developed by TEDRI as its competitive products for solar and wind energy industry.

### *To promote institution's accelerator production*

The State encourages research institutions engaged in technology development and transfer their scientific and technological achievements to industrial production independently or in collaboration with other enterprises. Institutes realize that the technology spinoff is one of the purposes of the mega-science projects. Table 2 lists the accelerator products exploited by the project related institutes. As examples, some institution's accelerator products are shown in Figure 3.

Table 2: Accelerator products of institutes

Institute	Accelerator products
IHEP	Magnets, microwave components, cryostats, ICT, irradiation accelerators, medical accelerators, etc.
IMP	Magnets, irradiation accelerators, vacuum freeze dryers, heavy ion treatment, etc.
NSRL	Accelerating structures, irradiation accelerators, medical accelerators, etc.
CAEP	Ferrite, amorphous magnetic materials, irradiation accelerators, high-voltage cables, high-speed camera, etc.
CIAE	Irradiation accelerators, NDT, cyclotrons, etc.
SINAP	Magnets, permanent undulators, electronics, irradiation accelerators, etc.



Figure 3: Some institution's accelerator products

IHEP has supplied a variety of magnets and microwave components for many applications in the world. In the aspect of electron linacs, IHEP has developed a series of irradiation accelerators of 10MeV/15kW standing wave linacs, 10MeV/20-40kW travelling wave linac (Fig.3a), as well as the 225kV/450kV/6MeV industrial computer tomography systems (ICT) and 6MeV X-ray sources. Recently, IHEP produced prototypes of undulators and cryostats for EXEFL and won a bid for mass production of 58 sets cryostats.

Based on the treatment terminal constructed in HIRFL, IMP undertaken research on cancer therapy with heavy ion beams. Recently, IMP is devoting itself to establish a demonstration base of heavy ion cancer therapy in collaboration with Shenda Group Co. Ltd.

Relying on the NSRL, the Hefei USTC Aike Science and Technology Co. Ltd. has developed a series of 10MeV/3-25kW S-band accelerating structures for irradiation, medical and non-destructive test (NDT) accelerators and provided irradiation facilities for customers (Fig.3b) [11].

The high quality Ni-Fe-Zn ferrite developed by CAEP during the DRGON-I construction has been applied in many fields home and abroad. The application of

amorphous magnetic material is also being extended to the electricity industry.

CIAE has developed a 30MeV proton cyclotron CYCIAE30 with beam intensity of 378  $\mu$ A (Fig.3c). Using the cyclotron, CIAE has supplied various short-life isotopes to most hospitals in Beijing. In aspect of electron machines, CIAE has produced various electric linac systems, including 14MeV and 10MeV/15kW irradiation facilities, self-shielding linacs for bacteria disinfection, 2MeV~9MeV NDT systems, fixed and movable cargo inspection systems with 6MeV/9MeV linacs [12].

In-vacuum undulators developed in SINAP have been operated in SSRF with excellent performance, and tens of such devices will be manufactured for SSRF upgrade. Recently, SINAP supplied a new in-vacuum undulator for PAS-II of Korea.

### To promote the accelerator industry

Construction of the large accelerator projects has promoted development of the accelerator industry. After years of efforts, tens of accelerator related enterprises were set up, involving scientific instruments, irradiation, ion implantation, non-destructive test, nuclear image as well as manufactures of magnets, power supplies, microwave components, vacuum devices, electronics and cryogenic apparatus and so on, forming an integrated accelerator industrial system in China [13].

Shanghai Kelin Technology Development Co., Ltd. is one of these enterprises. Founded in 1989, the company has taken on the production of magnets, wigglers, undulators, bunchers, vacuum components, and RFQ cavities for BEPC, HLS, BEPCII, HIRFL-CSR, CSNS and BRBF. The company also produced magnets and vacuum devices for PEP-II, KEK-B and J-PARC. The Kelin has now dedicated in production of RFQ accelerators and proton therapy devices [14].

### To promote regional economy

The construction of mega-science projects has obtained full support from the local government. In the meantime, construction of the projects has promoted the regional economy in the aspects of scientific research, technology development, talent support, infrastructure upgrade, and also employment. The R&D platforms jointly established by institutions and industry play an essential role in the long term development of the regions. IHEP is the core institute of the Capital Center for Radiation Technology & New Material Research and the Engineering Center for Radiation Image Technology and Equipment. IMP and SINAP have been developing the ion therapy facilities, which will greatly effect on the medical and health undertakings as well as regional economy. CSNS is being constructed in Guangdong. Based on the CSNS project, CAS and Guangdong Province have implemented a comprehensive strategic partnership. In the aspect of spinoff of accelerator technology, a non-power nuclear technology park is planed in Dalang where CSNS is constructed, including industrial irradiation, ICT and RFQ accelerators.

### To promote accelerator application in China

The construction of the accelerator projects and the significant progress of accelerator industry have greatly promoted the application of accelerators in the fields of research, industry, agriculture, nuclear transmutation, energy sources, environment, medicine and so on [13]. The accelerator products with “designed and made in China” can be seen everywhere in these application fields.

## COLLABORATION BETWEEN ACADEMIA AND INDUSTRY

The collaboration between academic institutions and industry for accelerator projects is illustrated in Figure 4.

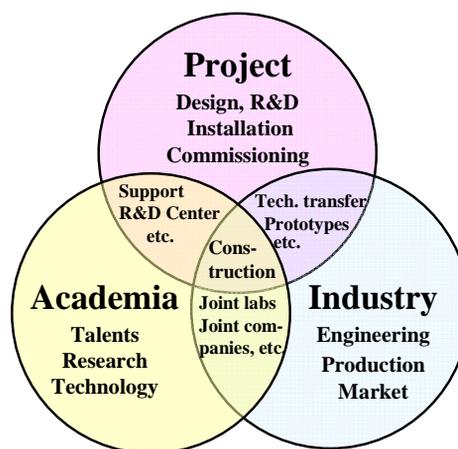


Figure 4: Collaboration between academia and industry

Construction of an accelerator project is common efforts of the project team, the academic institution and industry. The project team is in charge of design of the accelerator, R&D for key technology, installation of the machine and commissioning till it puts into normal operation. The institution provides manpower, talents as well as the research & technical supports. Acquiring the knowhow about specialities from the project team and the institution through technology transfer and prototyping, the industrial enterprises carry through mass production of accelerator components. The institutions carry on R&D with certain platforms, the R&D center of IHEP as an example, in order to transfer the specific technology of the projects onto the products for application. For industrialization, institutions need to collaborate to industry with joint labs and joint companies and so on.

This is a general approach of academia-industry collaboration in the principle of “combination of production sectors, schools and research sectors” in China. In practice, there are various ways towards industrialization of accelerator technology.

### Institutions directly produce accelerator products

As described in the previous section, the institutions may apply the technology developed in project construction to exploit accelerator products in their machine shop or in collaboration with industry. In this

way, the institutions need to set up a technical development sector to conduct the R&D activities, production and market. Very often, this is a step towards establishment of independent companies in order to extend the business.

### *Institutions establish high-tech companies*

IMP developed its first vacuum freeze dryer in 1994 based on the technology accumulation from HIRFL. A few production lines with such dryers were produced in the following years. To meet the growing demands from high quality green foodstuff market, the Lanzhou Kejin Vacuum Freeze Dry Technology Co. Ltd was established in 1999. Its key technological members are those who have worked long in HIRFL and are well experienced both theoretically and practically in technological fields concerning food freeze dryers in mechanics, vacuum, refrigeration, thermal technique, electronics and automatic control. After years' efforts, the company has become a leading enterprise in China engaged in food freeze drying and design, manufacture, installation and test of the facilities.

### *Institutions and enterprises set up joint R&D platforms to promote industrialization*

The Wuxi EL PONT Radiation Technology Co. Ltd. is used to work at high-voltage accelerator production and their application. Taking advantage of electron linac technology of BEPC, IHEP and EL PONT established the Electron Irradiation Accelerator Engineering Research Center of Jiangsu Province in 2007 as a province level R&D platform. Since then, EL PONT and IHEP have worked closely together in the research and development of industrial irradiation accelerators and their application. With the joint efforts, the 10MeV/20kW S-band irradiation linac were successfully accomplished and put on market. A 10 MeV/30kW linac system is in progress.

### *Institutions or its relying companies and enterprises establish joint companies*

The Shandong Huate Magtenism Co. Ltd. is a top-ranking enterprise in the fields of magnetic separators, de-ironing separators, coal mining equipments, metal detecting devices, and others. IHEP has developed superconducting technology in the BEPCII construction. To upgrade the products of the company, Huate and IHEP signed an agreement on collaboration in development and production of superconducting de-ironing separators in 2006. For two years, engineers of both sides worked together and the first superconducting de-ironing separator was produced in 2008 with high magnetic field of 4320 Gs. The superconducting separators have now become Huate's competitive products [16].

### *Institutions transfer technology to enterprises for industrial production*

Founded in 2001, the Vanform Electron Linac Technology Co. Ltd. is a high-tech enterprise in the field

of production and application of the irradiation electron linacs. The company imported the 10MeV/15kW electron linac technology from IHEP. With a close collaboration with IHEP, NSRL and other institutions, Vanform has carry out the R&D for 10MeV/(1-60)kW series electron linacs and their commercial production [17].

The high-tech industrialization is an extension of the technology innovation. The process of accelerator technology industrialization described above may be summarized as following: based on the technology developed in large accelerator projects, the institutions perform further research according to demands of market, and establish some R&D platforms with industry to carry out the engineering development; the industrial enterprises carry through the large-scale production and go on the technology innovation as a main body in collaboration with institutions.

We have come from a long way. There still a long way to go before talking about particle accelerator industrialization in China.

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