RESEARCH ACTIVITIES RELATED TO LOW ENERGY ACCELERATORS IN CIAE

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Abstract

In the last a few years, several low energy accelerators were developed in China Institute of Atomic Energy (CIAE) including the different energy, electron LINACs and Cockcroft-Walton machine for high intensity deuteron beam generation. And various R&D for the proposed project, the Upgrade Project of Beijing Tandem Accelerator Laboratory were carried out, such as the ion source and injection line of 100 MeV H- cyclotron, the target-source system of the isotope separator on line, et al. CYCIAE-30 is a 30 MeV medical cyclotron went into operation in 1995. Its recent operation status and isotope production will be described in this paper. The modification of the 2×13 Tandem accelerator will be also introduced briefly. Its accelerating tubes will be replaced this year and the terminal voltage will be increased to 15 MV expected. The research activities related to Accelerator Driven Subcritical system are being implemented recently in CIAE. Its progress will be reported as a separate talk in this conference.

1 UPGRADE PROJECT OF BEIJING TANDEM LABORATORY

For productions of intense proton and radioactive ion beam (RIB) used in fundamental and applied research, e.g., neutron physics, nuclear structure, material and life sciences and medical isotope production, a upgrade project of Beijing Tandem Laboratory was proposed by China Institute of Atomic Energy (CIAE) in 1999, which is a revised version of the previous proposal, "Beijing Radioactive Nuclear Beam Facility (BRNBF)". In the renewed proposal, a 100 MeV cyclotron is selected instead of the 70 MeV one so as to get more application by the cyclotron itself. The outline of the upgrade project is shown in Fig. 1. It includes a 100 MeV cyclotron, an isotope separator on line system, modification of the existing tandem, a super conducting Linac booster, various experimental terminals and isotope production stations. Recently, we are planning to start the detail design for the upgrade project. The proposed schedule is listed in the table 1 and the layout of upgrade project is shown in Fig. 2 next page. More than 40 proton-rich beams and 80 neutron-rich beams with beam intensity higher than 10^6 pps will be provided by this facility.

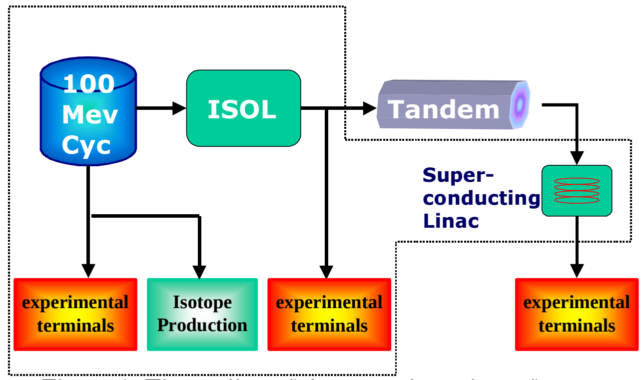

Figure 1: The outline of the upgrade project of Beijing Tandem Laboratory.

Table 1: Time schedule of the Upgrade Project

Item	2001	2002	2003	2004	2005	2006	2007
Physics Design	┅	━					
Engineering Design		┅━					
Civil Engineering			━	━			
Fabrication &Order			━	━	━		
Test & Installation				━	━	━	
Commissioning (Cyclotron)						━	
Commissioning (ISOL)						━	━
Commissioning (Tandem for RIB)						━	━
Commissioning (Linac)					━		

1.1 100 MeV H- Cyclotron

1.1.1 General Description

The driving accelerator, 100 MeV H- cyclotron will provides 75 MeV ~ 100 MeV, 200 μA ~ 500 μA proton beam. For a final energy of 100 MeV or below and beam intensity of less than 1 mA, a compact magnet and a H- acceleration with stripping extraction might lead to a smaller and cheaper machine. Some of the construction experiences from the 30 MeV medical used cyclotron built in CIAE 7 years ago can be used for the new machine development. Those are the reasons we select the compact type of cyclotron. The machine will own the following features:

- The compact magnet will provide high enough flutter and lower first harmonic though the harmonic coils will be absent.

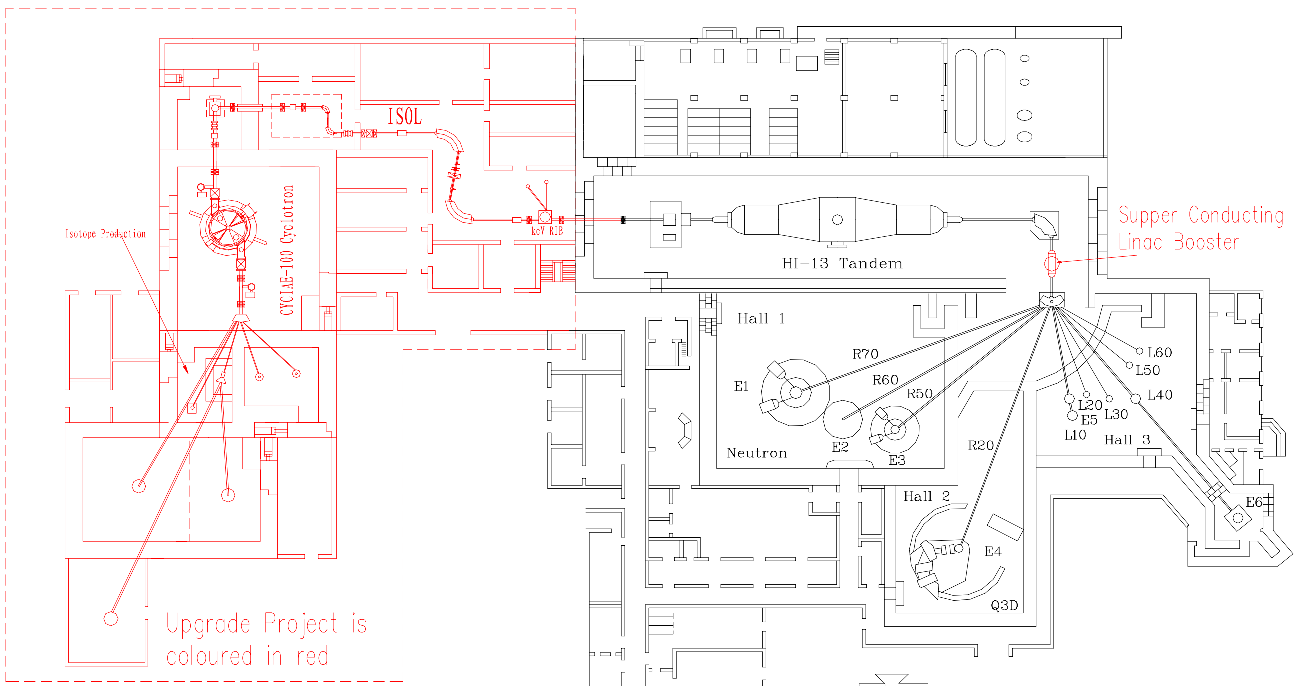

Figure 2: The layout of Upgrade Project of Beijing Tandem Laboratory

- The H- acceleration permit us to extract the beam by stripping from the compact machine.
- The external source not only provides higher beam intensity, but also shows us a possibility to provide pulse proton beam by the cyclotron.
- The magnetic field of less than 1.4 T in the hill region will guarantee a low rate of dissociation of H- ions during the whole acceleration.
- Two triangle, half wave cavities are installed into the valleys of the magnet. They are connected together at the central region of the machine. The RF power from coaxial transmission line is coupled into the cavities capacitively.

1.1.2 Specification for main parameters

The specification for main parameters of principal parts are given as following:

- Beam

Extracted	Proton	Accelerated	H^-
Energy		75 MeV ~ 100 MeV	
Beam intensity		200 µA ~ 500 µA	
Number of Extraction Port		2	

- Ion source / Injection

Source		Injection	
Type	Multi-cusp	Energy	~ 30 kV
Current	> 5 mA	Inflector	Spiral

- Magnet

Number of Ssctors	4
Sector Angle	50°
Field in Hill	1.4 T
Field in Valley	0.15 T
Radius of the Pole	1920 mm
Inner Radius of the Yoke	2400 mm
Outer Radius of the Yoke	3100 mm
Gap between the valley	1600 mm
Gap between the Hills	40 mm
Total Weight of Iron	475 t

- Main Coils / Power Supply

Ampere-Turn Number	70 kAT
Current Density in Coil	0.55 A/mm^2
Copper Weight	24 t
D.C Power	20 kW
Stability of power supply	1.0×10^{-5}

- RF System

Number of Dees	2	Dee Voltage	50-60 kV
Dee Angle	34°	Harmonic Mode	4
Frequency		49.6 MHz	

1.1.3 Preliminary Study for sub-system of cyclotron

- Magnet

Four simple sectors structure is selected for the main magnet. 2D and 3D field computation have been done for the dynamics consideration. The isochronous field can be achieved by some adjustment of the shimming bar attached at both sides of the sectors. Fig. 3 displays its field distribution. The spiral sectors will be tried to get a stronger axial focus. The field distribution based on spiral sector magnet is calculated recently. The model of magnet from a FEM code is shown in Fig. 4.

- RF Cavity

The geometry of two half wave cavities which are installed in the valley is illustrated in Fig. 5. The cavity can be equivalent to an axial symmetrical structure so as to calculate the frequency by a 2D code, such as SUPERFISH. Various dimension of the cavity are tested and the results are listed in table 2. The 3D calculation based on finite element method is also performed. Fig. 6 shows the electromagnetic field in the cavity.

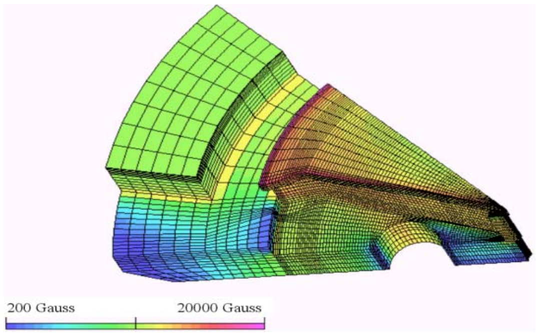

Figure 3: The Magnetic Field Distribution.

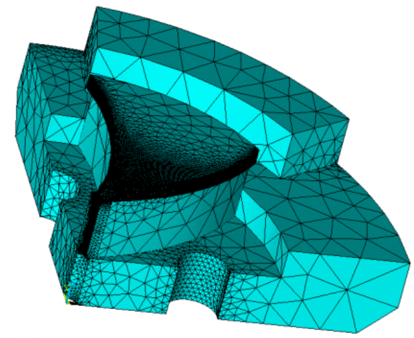

Figure 4: The model of Magnet with spiral sector.

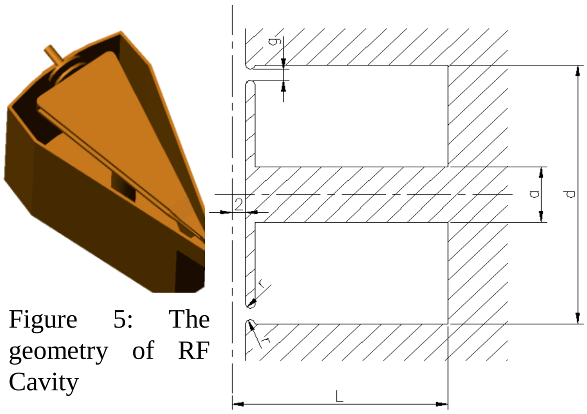

Figure 5: The geometry of RF Cavity

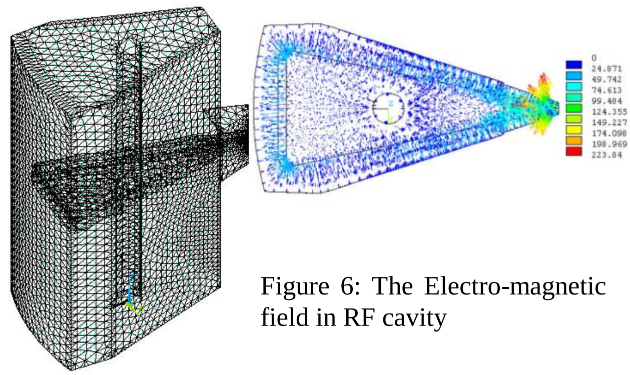

Figure 6: The Electro-magnetic field in RF cavity

Table 2: Resonance frequency calculated by a 2D code

r/cm	d/cm	L/cm	g/cm	a/cm	f/MHz
1	73	80	3	40	51.752
1	73	80	3.5	38	51.468
1	73	70	3.5	33	50.889
1	73	70	3	35	51.114
1	73	70	2.5	37	51.116
1	73	65	3	32	50.455
1	73	65	2.5	34	50.427
1	73	65	2	37	51.009
1	73	60	3	30	50.915
1	73	60	2.5	32	50.880
1	73	60	2	34	50.424
1	73	55	3	27	50.527
1	73	55	2.5	30	51.509
1	73	55	2	32	51.036

- Test stand for ion source and injection line

Only the concept design of the compact, 100 MeV H- cyclotron is completed currently. The detail dynamics and parts design will be implemented this year, with some collaboration from other institute expected. To get higher beam intensity, an external multi-cusp ion source is used for the cyclotron. The source and axial injection line have been investigated in last two years. Based on the rough consideration of cyclotron's dimension, the distance from the extraction hole of multi-cusp source to the central region of the machine is 2191 mm. The injection line includes a combine function x-y steering magnet, an Einzell lens, a buncher, a solenoid lens and an inflector. The test stand of the H- ion source and axial injection line is shown in figure 7. Recently, 5.2 mA DC beam can be transported to the inlet of the inflector.

Figure 7: The test stand of the H- ion source and axial injection line.

1.2 Isotopes Separator on Line

The ISOL system is composed of the target/ion source system, match lenses, 90° magnetic analyzers, charge exchange canal and isobar separator. All of the components, except the isobar separator, are located on a high-voltage platform with potential up to 300 kV. The platform connects the primary proton beam line and the isobar separator system beam line by two accelerator tubes. In order to achieve a high performance isobar separation, two 100°, ρ=2.5m opposite bending magnets at ground potential have been designed. The mass resolution is about 20000. The configuration of ISOL system is given in Fig 2.

1.2.1 Simulation of the diffusion, adsorption and effusion processes

The target system design is one of the key problems in the ISOL facility for RIB generation. To check the factors which may affect the efficiency and optimize the design of the system, the diffusion and adsorption processes in the target materials are simulated so as to study the release time of radioactive species from the uniform or Gaussian distribution, cylindrical, spherical or planar target materials operated at the different temperatures based on the idea of using ion implantation at HRIBF for the selection of RIB targets [1]. One of the simulation results is shown in figure 8. The effusion process from the surface of the target material to the ionization chamber of the online ion source is also investigated. The Monte-Carlo techniques are used for the numerical simulation based on the measurement data of surface physics from ZFK, Germany [2]. The experiential formulas and the tables of characteristic effusive-flow times for various particles through tubes of different dimension and materials are extracted from the simulation. One can design the effusion tube and select the material for the tube by using the formulas and the tables [3].

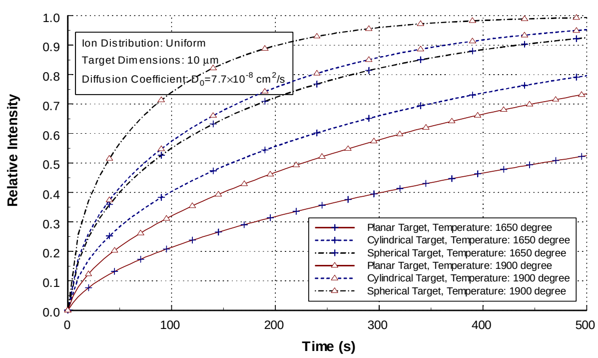

Figure 8: The release time of 17F diffusing from ZrO_2 at different operation temperature.

1.2.2 Ion Source

A modified version of the ISOLDE type electron beam plasma ion source will be chosen as the main source, which has been selected and redesigned for HRIBF facility at Oak Ridge National Laboratory[4]. The on line test system which is shown in figure 9 is being installed at the downstream of the Tandem to generate the keV RIB, such as the ^{62}Zn.

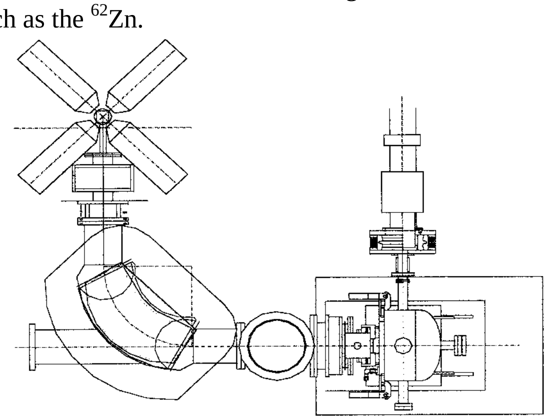

Figure 9: The ISOL test system for keV RIB generation.

1.3 The supper conducting linac Booster

In order to extend the region of stable and the radioactive ion species with energy higher than relative Coulomb barrier, a booster following the tandem accelerator will be built, that is a super conducting booster.

The design goal of our linac booster is to have a energy gain of 2 MeV/q, table 3 shows the main parameters for some particles accelerated by the superconducting linac. In table 3, the ion species from Al to Cs with different probability charge state q at post-accelerator, it has listed their energy gains and the energy gains per charge for various particles.

The sketch of the booster linac is shown in Fig 10. A new post stripper accepts the high energy beam coming from the tandem, in order to increase the ions charge state. The 90° bending magnet can select desired charge state into the linac.

Table 3: The energy gains for various particles

P	Z	A AMU	q	W_{in} MeV	β	W_{out} MeV	ΔW MeV	ΔW/q MeV/q
Al	17	35	16	108	0.081	147.78	39.78	2.48
Ni	28	58	22	120	0.066	177.35	57.35	2.61
Ag	47	108	29	144	0.053	216.72	72.72	2.51
Sn	50	118	29	156	0.050	230.91	74.91	2.50
I	53	127	30	156	0.051	229.07	73.07	2.44
Cs	55	133	31	156.	0.050	230.20	74.20	2.39

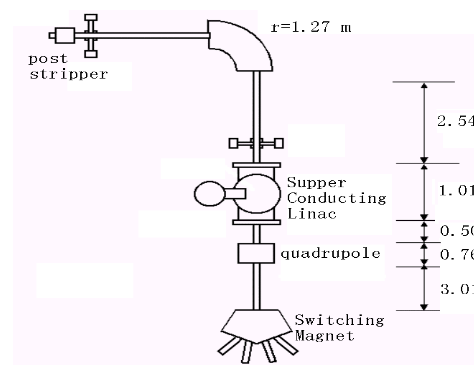

Figure 10: The sketch of the booster linac

The mode of the resonator for linac sections is the cylindrical coaxial quarter wave resonator (QWR), which was very successful developed at Weizimann Institute, University of Washington, Stony Brock, Legnaro Laboratory and JAERI. Their experience shows that the excellent frequency stability, the simple structure for manufacture and balance electrically, the broad curve of the transit time factor, the low peak surface field values and wide energy per nucleon range together with the low cost constitute are the important advance in technology of super conducting resonators advance in technology of super conducing resonators for heavy ion linac.

Our super-conducting booster is composed of four QWR cavities, which are located into one cryostat, which has a diameter of 1.1meter. We choose the cavities of the optimum β=0.07 for frequency of 108 MHz.

The R & D of the mechanical and electrochemical preparation of the substrate of the cavity, the technology of the Niobium-sputtered copper Quarter wave resonators have been testing in Peking University.

When the linac machine is used, the beam should be bunched into a pulse beam. It's necessary to substitute a double-drift harmonic buncher for the existing single drift buncher system. The capture efficiency will be increased to about 60%. Table 4 shows the bunching efficiency of the double-drift buncher for various particles.

Table 4: The capture efficiency

Particle	p	C	S	Cu	Cs
Initial energy (keV)	120	120	300	300	300
Initial pulse (ns)	103	106	104	90	105
First buncher V1(kV)	7.77	2.37	5.74	5.99	2.83
Second buncher V2(kV)	-2.55	-0.87	-2.1	-2.2	-1.05
Capture efficiency	62%	64%	62%	54%	63%
Phase at 108Mhz	$\pm 10^{0}$	$\pm 34^{o}$	$\pm 20^{o}$	$\pm 26^{o}$	$\pm 44^{o}$

2 MEDICAL ISOTOPES PRODUCTION BY 30 MEV H- CYCLOTRON

A 30 MeV H- cyclotron was built and went into operation in 1995, which was reported elsewhere. Since then, various medical use isotopes have been produced and provided to a few tens hospitals in China and abroad, such as ^{201}Tl, ^{18}FDG, ^{57}Co, ^{67}Ga, ^{68}Ge, ^{109}Cd, ^{111}In and ^{186}Rb. The isotopes can be supplied all year around. Another isotope, ^{103}Pd just was developed this year and ^{123}I will be completed next year. The available beam time and the output value of isotopes in last a few years are illustrated in Fig 11.

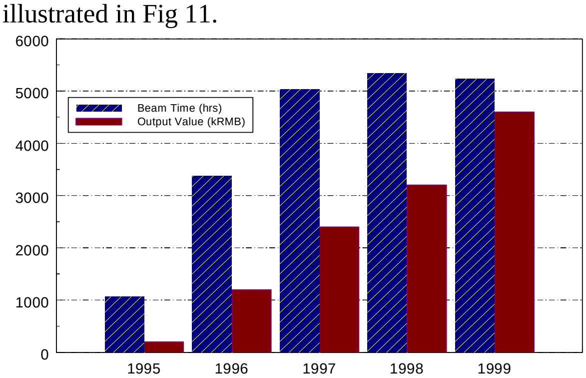

Figure 11: The beam time and output value of isotopes

3 LOW ENERGY ELECTRON LINACS

Different kinds of low energy electron linacs with energy from 1.5 MeV to 9 MeV have been developed for the industrial no-damage detection system or irradiation facilities. 21 linacs built in CIAE are listed in table 5. In the table, the X band machine with frequency 9300 MHz is small enough to easily install on a truck so as to integrate a flexible detection system. The S band machine with frequency 2998 MHz is designed and fabricated within only 58 days. Recently, We intend to develop the higher energy, high power linac, e.g. the 15 MeV machine used for digital radiography or industrial computed tomography, the 10-12 MeV, 2-20 kW machine for irradiation sterilization etc.

Table 5: The low energy electron linacs built in CIAE

Energy (MeV)	Band	f (MHz)	RF Power Source	RF Power (MW)	Pulse Width (μs)	Amount
14	S	2856	Klystron	15	2.5	1
4	S	2998	magnetron	2	4	3
3	S	2998	magnetron	2	4	2
1.5	C	5301	magnetron	1	3	1
2.5	X	9316	magnetron	1	3	4
6	S	2998	magnetron	2.6	4	1
9	S	2856	Klystron	5	5	8
5	L	1300	Klystron	3	12	1

4 OTHERS

4.1 High Power, Pulse Electron Accelerator

For the fundamental researches on Inertia Confinement Fusion (ICF), a six beams high power KrF excimer laser system have been built. Two high power, pulse, relativistic electron accelerators are adopted in the system, serving as pre-amplifier and main amplifier.

Table 6: The principal parameters of two amplifiers

	Impedance	Pulse Duration	Diode Voltage	Output Energy
Pre-amplifier	7 Ω	100 ns	400 kV	30 J
Main amplified	2.5 Ω	200 ns	600 kV	400 J

4.2 600 kV ns pulse neutron generator

A 600 kV Cockcroft-Walton machine was built for the ns pulse neutron generator some experiments, e.g. neutron and γ-ray standards for radio-metrology, neutron integral experiment at 14 MeV and secondary neutron double differential cross section measurement etc.

Table 7: The comparison with similar neutron generators

Lab.	E_d (keV)	Ion source	Beam (μA)	Sport (mm)	Width (ns)	f (MHz)	Intensity (n/s)
CIAE	600	RF	≥30	ϕ5-10	1.0	1.5	1×10^{10}
LLNL	400	RF		ϕ6	1.5	2.5	5×10^{10}
JAERI	400	RF	20 or 40	ϕ15	2.0	1 or 2	0.5 or 1×10^{10}

5 ACKNOWLEDGEMENTS

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