SCIENCE CHINA
Physics, Mechanics & Astronomy

• Research Paper •
Radioactive Nuclear Beam Physics and Nuclear Astrophysics

August 2011 Vol.54 Suppl. 1: s14–s17
doi: 10.1007/s11433-011-4422-x

BRIF and CARIF progress

LIU WeiPing*, LI ZhiHong, BAI XiXiang, WANG YouBao, GUO Bing, PENG ChaoHua, YANG Yi, SU Jun, CUI BaoQun, ZHOU ShuHua, ZHU ShengYun, XIA HaiHong, GUAN XiaLing, ZENG Sheng, ZHANG HuanQiao, CHEN YongShou, TANG HongQing, HUANG Li & FENG BeiYuan

China Institute of Atomic Energy, P. O. Box 275(1), Beijing 102413, China

Received January 27, 2011; accepted April 20, 2011; published online August 3, 2011

China Institute of Atomic Energy (CIAE) is currently constructing Beijing rare ion beam facility (BRIF) and is proposing China advanced rare ion beam facility (CARIF). This paper is aiming at introducing the progress of BRIF project and the conceptual design CARIF. The ISOL type facility BRIF under construction is composed of a 100 MeV 300 μA proton cyclotron, an ISOL with mass resolution of 20000, and a super-conducting LINAC of 2 MeV/q, and will be commissioned in 2013. CARIF facility proposed is planned to use both ISOL and PF techniques. It is based on a China advanced research reactor CARR that was critical, with ISOL separation of fission fragment, post acceleration to 150 MeV/u, and fragmentation of neutron-rich fission fragment beam like ^{132}Sn. Such unique combination will allow CARIF to deliver beam intensity better than the best world facilities by more than one order of magnitude.

rare ion beam, ISOL, PF

PACS: 28.50.-k, 29.25.Rm, 29.38.Gj, 29.38.Db, 29.20.E

1 Introduction

Currently, there are two major nuclear physics centers in China. The China Storage Ring (CSR) is located at the Institute of Modern Physics (IMP) Lanzhou. CSR was commissioned in 2008, and it can deliver stable and unstable heavy-ion beams with the energy range of 10 to 1100 MeV/u. China Institute of Atomic Energy (CIAE) is currently equipped with Tandem accelerator, the Tandem is delivering the stable heavy-ion beam with energy of up to 15 MeV/q. CIAE is currently constructing Beijing rare ion beam facility (BRIF) and is proposing China advanced rare ion beam facility (CARIF). This paper aims at introducing the progress of BRIF and CARIF.

Currently, the rare ion beam facility can be classified into projectile fragmentation (PF) and isotope separation on line (ISOL) types. The BRIF under construction is an ISOL type facility, it will be commissioned in 2013. CARIF facility proposed is planned to use both ISOL and PF techniques.

The ISOL facility is good at precise physics with high quality beams. The beam isospin is limited to near beta stability line due to the reaction mechanism and long separation time of ion source. To achieve this, sophisticated target and ion source technology must be handled. Due to this challenge, there is less ISOL facility commissioned in recent years compared with PF facility. Some of the current operational facilities are, ISAC, REX-ISOLDE, and HRIBF etc [1,2].

The PF facility, on the other hand, is good at delivering extreme isospin of beams, so that the drip line physics research can be done. It uses in-flight separation method to select beams. This means beams are with the energy spread of Fermi momentum and the energy loss straggling and with

*Corresponding author (email: wpliu@ciae.ac.cn)

the considerable mixture of nearby species in stability line side. Some of the currently operational facilities are MSU, GANIL, CSR, RIBF, etc. The facilities under construction are FRIB, and FAIR, etc.

There are new facilities under discussion, which tried to use the combination of ISOL and PF techniques, such as SPIRAL2 [3], KORIA and EURISOL [4], as well as CARIF.

2 BRIF status

BRIF aims at physics with unstable beams in the energy range of 100 keV to 10 MeV/u. The physics topic will be covered in the field of rp process, reaction studies of N=Z nuclei, nuclear decay and the study of neutron rich nuclei.

BRIF will be based on the existing 15 MV tandem accelerator. A compact cyclotron, with proton beam energy of 100 MeV and intensity of 300 μA will be built upstream tandem. An ISOL with the mass resolution of 20000 will be constructed in between to convert intense proton beam into rare ion beams that suitable for tandem injection. After the tandem, a super-conducting LINAC sector will be installed to further boost the beam energy by 2 MeV/q. The species of unstable beam is includes proton-rich ones via fusion evaporation and charge exchange reactions. However, when ^{238}U target is used, neutron-rich beams can be produced via proton induced fission reaction. The ISOL mass resolution of 20000 is designed for the purpose of separating the isobars from fission products.

BRIF project was submitted to the government in 1997, and the evaluation process was started then. The project was approved in 2003, and its feasibility plan was approved in 2004. Due to the increased budget requirement, the revised feasibility plan was submitted in 2008, and was approved in 2009.

2.1 The cyclotron

The driving accelerator, 100 MeV H^- cyclotron will provide 75–100 MeV continuous proton beam. Its beam intensity is designed to be 300–500 μA. A cyclotron with compact magnet and an H^- acceleration with stripping extraction design was adapted in the sense of compactness and economy. The construction experiences from building the 30 MeV cyclotron in CIAE dedicated for medical use is a good starting point for the new machine development.

The machine will have the following features. The compact magnet with deep valley will provide high enough flutter and lower first harmonic though the harmonic coils will be absent; The H- acceleration will allow us to extract the beam by stripping instead of by electrostatic deflector, which will increase the extraction efficiency up to almost 100%. The external source not only provides higher beam intensity, but also gives us a convenient way to maintain the ion source and keep a better vacuum in the main chamber.

Up to now, the main magnet of cyclotron is in final assembly stage. Two main magnet coils are ready for assembly. Two 100 kW RF power supplies were tested. And the vacuum chamber and elevating system will be completed soon.

2.2 The ISOL and LINAC

The ISOL target/ion source system is well designed for radio activity shielding with modular components. The high resolution magnets have the mass resolution of 20000. The ISOL magnets are finished, target-source fabrication is in progress.

In order to extend the region of stable and the radioactive ion species with energy higher than Coulomb barrier, a booster following the tandem accelerator has to be planned to build, that is a super-conducting booster. The design goal of our LINAC booster is to have an energy gain of 2 MeV/q. A new post stripper accepts the beam coming from the tandem accelerator, in order to increase the ions charge state. The 90 degree bending magnet can select desired charge state into the LINAC. The super-conducting booster is composed of four QWR cavities, which are located in one cryostat, which has a diameter of 1.1 m. We choose the cavities of the optimum beta of 0.07 for the frequency of 108 MHz.

SC linac design is finished, and all the fabrication is in progress. The civil engineering will be started by the end of 2010. The BRIF will be commissioned in 2013.

For further increasing beam energy, aiming at the energies higher than coulomb barrier up to mass 100, we are planning to install the retired super conducting LINAC from Stony Brook of New York University.

The overall configuration of the BRIF project, including the coming super conducting LINAC, is shown in Figure 1.

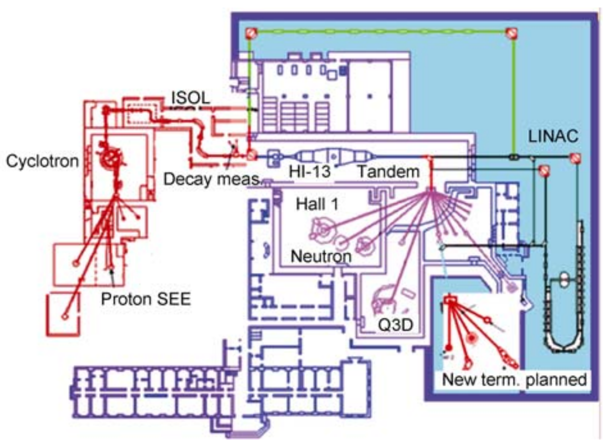

Figure 1 The overall configuration of BRIF project.

3 The CARIF proposal

3.1 Introduction

For exploring the area of extreme isospin, currently, people reach Z=30 and Z=10 for proton-rich and neutron-rich drip line, respectively, still far from the region of shell evolution and astrophysical r-process. This is mainly limited by the RIB intensity limitation from the narrow isospin range of stable beams. To overcome this limit, a new producing concept was proposed.

One of such concepts is using neutron-rich fission fragment beam from reactor thermal neutron induced ^{235}U fission [1]. ISOL will select “easy but good” fission fragment, i.e., those with long half life and fission yield, like ^{132}Sn. The selected ions will further be accelerated. Then, the beam will be sent to the target for fragmentation. Currently, the proposed EURISOL [4], CARIF adopted this idea.

There are advantages and short comings of this approach. The advantage is that the beams will have 5–8 more neutrons than stable beams, with the cross section increasing by 6–9 order; whereas the short comings are the re-accelerated beam intensity which is weaker by 5–6 order. For example, RIBF will deliver ^{238}U with 10^{12} pps, but this kind facility has only$10^{9–10}$ pps for ^{132}Sn. Together, the net gain is 1–2 order or more beam intensity enhancement. This approach makes the combination of the well established technique, thus ensures the feasibility of realization. The selection criteria of “good and easy beam” are long half life and high yield, that means a normal ISOL can do a good job. The fission beam intensity of 10 pnA order is easy for beam acceleration, because there is no limitation of space charge and beam diagnostics. The conceptual design of such kind of facility can be seen in Figure 2.

3.2 The CARR research reactor

China advanced research reactor (CARR) project was approved in 1997, its civil engineering was finished in 2005, and its reactor core was finished in 2007. CARR reached its first criticality in May, 2010, and will reach full power by the end of 2011. CARR is a multipurpose, high performance research reactor. Through light water cooling and heavy water reflecting, it can deliver neutron flux of 8×10^{14} cm^{-2} s^{-1}, with thermal power of 60 MW.

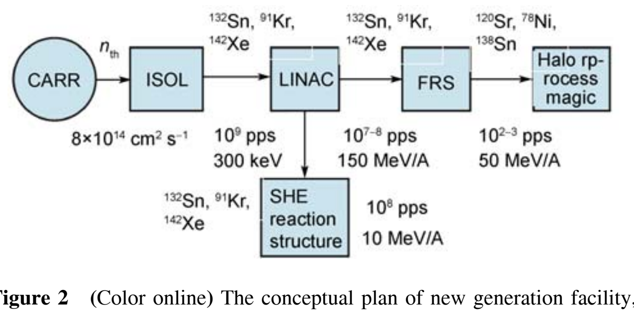

Figure 2 (Color online) The conceptual plan of new generation facility, where the beams, energies as well as physics are indicated.

There are a number of research reactors in the world, namely ILL, FRMII, other smaller reactors, and CARR with neutron flux (horizontal, cm^{-2} s^{-1}) of 1.5×10^{15}, 6×10^{14}, 3×10^{14}, and 8×10^{14}, respectively. Based on research reactor, some similar proposal were proposed, such as PIAFE in ILL, and MAFF in FRMII [4,5]. Although they are not finally approved, they provide a good reference for CARIF project.

3.3 CARIF design

Based on the above consideration, the initiative CARIF design was made. The thermal neutron from CARR reactor will impinges 5g ^{235}U target in in-pile ion source. The fission fragments like ^{132}Sn and ^{91}Kr are mass separated by ISOL system, and after charge breeder, they are post accelerated by super-conducting LINAC to the energy of 150 MeV/u. Up to here, the system is just a ISOL facility, with reactor as driving machine. Then, a further fragmentation and secondary beam line selection were made, as normal PF facility. The schematic figure of CARIF configuration is shown in Figure 3.

3.4 The technical challenges and solutions

There are a number of technical challenges, namely, high temperature and high dosage target/ion source, effective extrication of fission fragment, effective isotope separation, high beam transmission of post acceleration stage, and so on.

The solutions can be found from various proposals and projects [3,6], among which, the PIAFE can give a very detailed plan of high power in-pile ^{235}U target; CARIBU in ANL under construction by using ^{252}Cf fission can give a good reference for ion source development; ORNL’s experience of separation and acceleration of ^{132}Sn to 10^4 pps can give the experience of acceleration of unstable beams; Studsvik reactor has handled 1 g ^{235}U target with 3×10^{11} cm^{-2} s^{-1} neutron which gives us a feasible solution of the target. They all show the feasibility of ISOL post acceleration of fission fragment beams like ^{132}Sn.

3.5 Neutron-rich beam intensities and physical chances

With unprecedented beam intensities, a number of exciting physics chances are opened. They are: adding single neutrons until drip line; discovery of new magic number; synthesis of super heavy elements by using neutron rich beams; exploring the giant halo structure; reaction and decay measurement of nuclei in astrophysical r-process; extending new decay modes such as βxn and ground state neutron decay. Needless to say, many applications can be done such as data measurement of n-rich nuclei and application of n-rich beams. The examples of beam intensities around ^{78}Ni is shown in Figure 4.

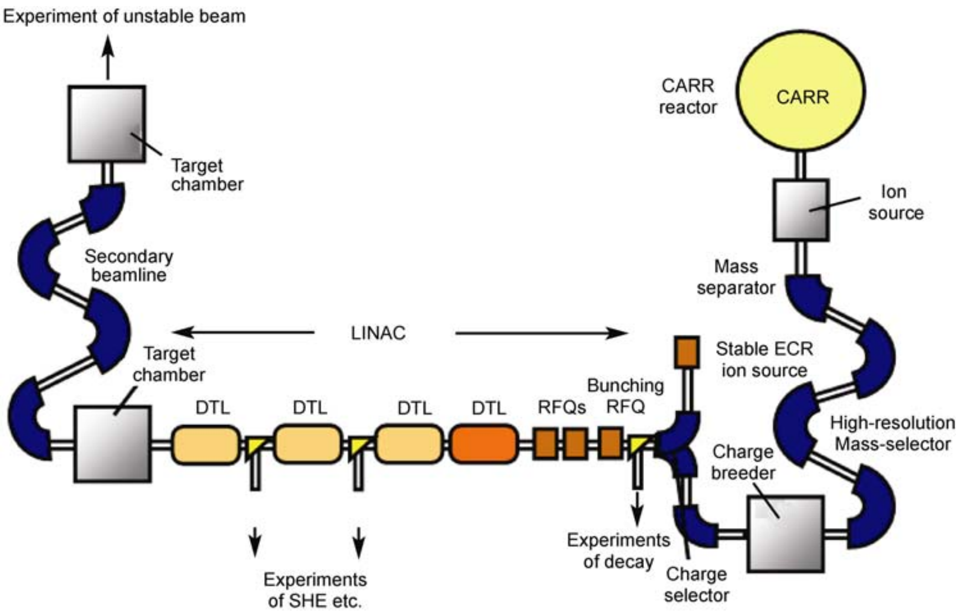

Figure 3 The instrumental plan of CARIF, where the main component and usage are indicated.

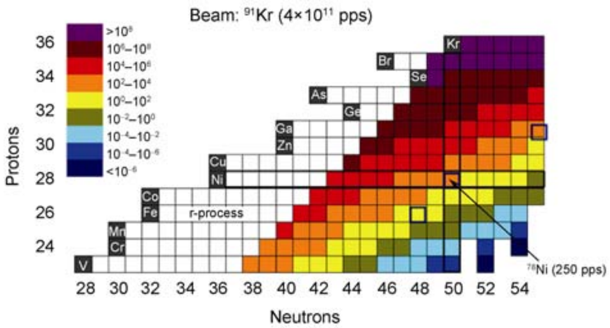

Figure 4 The examples of beam intensities around ^{78}Ni by using ^{91}Kr fragmentation.

3.6 Proposal progress and summary

The CARIF proposal initiated the first internal discussion in January 2010. In June 2010, the application was submitted to CAEA and then to NDRC. In October 2010, the proposal is under evaluation in NDRC. In July 2010 and after, CARIF plan was presented in nuclear physics community in China. Internationally, the first idea of CARIF was discussed in RCNP in January 2010. In July 2010, a brief report was presented in WG9/IUPAP, Vancouver, and then cited as an example for future development of RIB facilities in the world by B. Fulton in INPC2010 conference invited talk. In October 2010, CARIF was presented in Seoul ANPhA symposium and ISNPA symposium in Beijing.

In summary, nuclear physics in CIAE will open up new opportunities, driving by BRIF and future CARIF. BRIF will be competitive ISOL facilities. If realized, CARIF will be a world unique facility, based on the commissioning research reactor CARR. By using the combination of advanced ideas and feasible techniques, CARIF will provide the extremely neutron-rich beam, with possibly higher intensity than the existing facilities. We wish to exchange ideas with people from similar facilities to tackle with common technique challenges, to make CARIF into reality in the near future.

This work was supported by CIAE innovative Fund of 2010.

1 Tanihata I. Radioactive beam science, past, present and future. Nucl Instrum Methods B, 2008, 266: 4067–4073
2 Ravn H L, Bricault P, Ciavola G, et al. Comparison of radioacitve-ion beam intensities produced by means of thick targets bombarded with neutrons, protons and heavy ions. Nucl Instrum Methods B, 1994, 88: 441–461
3 Lewitowicz M. The SPIRAL2 project: Physics and challenges. Acta Phys Polo B, 2009, B40: 811–819
4 Vervier J. The EURISOL report. GANIL, 2003
5 von Egidy T, Kienle P, Köster U, et al. The Munich accelerator fission fragments (MAFF) at the new reactor FRM II. Acta Phys Slov, 1999, 49: 107–116
6 Kester O, Habsa D, Groß M, et al. RNB production with thermal neutrons. Nucl Phys A, 2002, 701: 71–77