# STATUS OF THE ISOL CYCLOTRON SYSTEM IN RISP*

J. Kang†, H. M. Jang, B. Kang, J. W. Kim, J. H. Lee, Institute for Basic Science, Daejeon, Korea

## *Abstract*

An ISOL system has been developed for providing neutron-rich RI beam to multi-disciplinary users by Rare Isotope Science Project (RISP) of the Institute for Basic Science (IBS) in Korea. The ISOL system is composed of proton driver, target/ion source station, mass separator, charge breeder, and A/q separator. A selected beam of interest is then injected into re-accelerator, which is a superconducting linac. A 70 MeV proton cyclotron was chosen as the proton driver to induce direct fission of UCx target. The final goal of beam power on target is 70 kW, which will be achieved gradually from 10 kW during post-RISP. Recently, commercial H- compact cyclotrons and high-intensity cyclotrons have been considered for its extension of multi-purpose uses. In this paper, the specifications of the cyclotrons along with concerned issues and the status of our procurement plan will be presented.

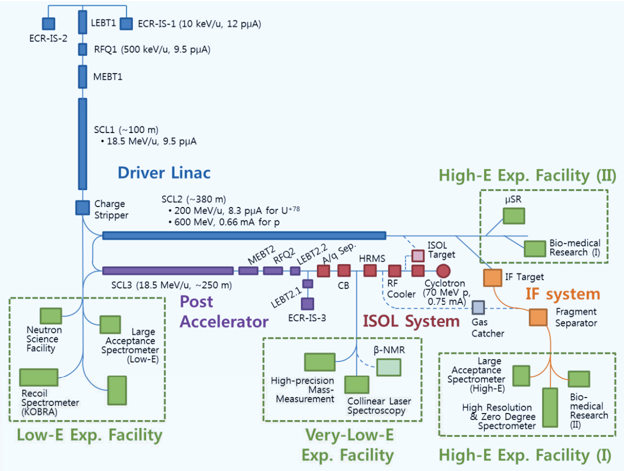

Figure 1: Conceptual diagram of the RAON.

## INTRODUCTION

RISP was launched to develop RAON, the name of the heavy-ion accelerator, in 2011. The RAON can utilize both the Isotope Separation On-Line (ISOL) and In-flight Fragmentation (IF) to produce rare isotopes for multi-disciplinary uses (see Fig. 1). The RAON is composed of a driver linac, an IF system, an ISOL system, a post-accelerator, high-energy experiment facility I&II, a very-low-energy experiment facility, and a low-energy experiment facility. The driver linac has two superconducting ECR ion sources, a LEBT, a RFQ, a MEBT, a low-energy superconducting linac (SCL1), a charge stripper, and a high-energy superconducting linac (SCL2). The IF system is employed of an IF target, a pre-separator, and a main separator. The driver linac can accelerate heavy ions up to an energy of 200 MeV/u with a maximum beam power of 400 kW. The ISOL system consists of a 70 MeV proton cyclotron, a target/ion source, a mass separator, a charge breeder, and an A/q separator followed by a post-accelerator system. Not only the IF system and the ISOL system operates independently but also the beam from the ISOL system can be injected via the post-accelerator and SCL2 to IF system for more exotic rare isotopes. The conceptual design and technical design studies on RAON accelerator systems have been conducted since 2012. RISP will be accomplished by the end of 2021.

ISOL system will use a proton cyclotron system as a proton driver and UCx targets to produce neutron-rich (n-rich) isotopes. The final goal is direct fission of $^{238}$U by 70 kW proton beam. A 70 MeV proton cyclotron and high-intensity deuteron cyclotrons have been considered to produce more than 70 kW proton beam. Cost, fabrication time, and feasibility aspects were taken into account to choose a suitable cyclotron for RISP.

## MAIN ISSUES

The operating plan of the cyclotron is to continuously supply the 70 kW proton beam on the UCx target uniformly over 300 hours for n-rich isotopes. Carbon stripper foil's lifetime, thermal control system of the UCx target, and beam losses inside a cyclotron are critical issues to satisfy the operating plan. The lifetime of a carbon stripper foil is about 20 000 μAh for 100 μg/cm$^2$ [1, 2]. It is not possible to meet the beam operating time by one carbon foil when the beam current is 1 mA. Applying a multiple foil extraction system with at least 15 foils is introduced, the required operating time can be achieved. However, the beam stop during foil replacement is unavoidable. In this situation, the thermal control of the UCx target and quick foil-exchange systems are necessary to maintain specific temperature of the target. In addition, radio activation inside a cyclotron is concerned about maintenance due to the beam losses by Lorentz stripping and vacuum dissociation during acceleration and extraction [3]. Even several percentage of beam losses at 70 kW can cause high radio-activation in a cyclotron. High vacuum pressure and/or high Dee voltage are needed to minimize the beam losses.

## CANDIDATES FOR AN ISOL DRIVER

A High-intensity cyclotron such as the PSI injector II cyclotron was debated at the beginning of the RISP. PSI injector II is a separated sector cyclotron and can accelerator the proton up to 72 MeV with 2.5 mA. A 70 MeV proton cyclotron was reviewed by ISOL group at the conceptual

---

* Work supported by Rare Isotope Science Project (RISP) through the National Research Foundation of Korea (NRF) funded by Ministry of Science, ICT and Future Planning (MSIP) (NRF-2013M7A1A1075764)

† gaenuinei@ibs.re.kr

design phase in 2012. At that time, commercial 70 MeV cyclotrons are in operation or planning by ARRONAX [4, 5] and SPES project [6–8], respectively (see Table 1). Moreover, deuteron compact or separated-sector cyclotrons have been discussed to take into account the efficiency of n-rich isotopes production rate and the diversity of research field through international review programs [9–11] (see Table 2). Even though deuteron cyclotrons are advantageous for high current, it is required additional components of a injector, a energy converter and radiation shielding blocks accompanying more budget and longer development time.

Table 1: The Specifications of Commercial Cyclotrons

| **Parameters** | **IBA (Belgium)** | **BCSI (USA)** |
|---|---|---|
| Energy | 35–70 MeV, | 35–70 MeV |
| Max. current | 750 µA | 750 µA |
| Extraction ports | Dual | Dual |
| Magnet sectors | 4 | 4 |
| Magnetic field (hill, valley) | 1.7 T, 0.12 T | 1.6 T, 0.12 T |
| RF harmonics | 4 | 4 |
| RF frequency | 62 MHz | 56.2 MHz |
| Ion source | Multicusp | Multicusp |
| Operating site | ARRONAX, France (2010) | INFN, LNL, Italy (2015) |

Table 2: The Specifications of Deuteron Cyclotrons

| **Parameters** | **Proton cyclotron** | **Deuteron cyclotron** | **Deuteron cyclotron** |
|---|---|---|---|
| Beam characteristics | 70 MeV,<br>$H^-$,<br>0.7–1 mA | 40 AMeV,<br>$D^-$, $H^{2+}$,<br>1–1.5 mA | 60 AMeV,<br>$D^+$, $H^{2+}$,<br>1–2 mA |
| Beam power | 70 kW | 120 kW | 240 kW |
| Pole radius | 1.35 m | 1.66 m | 2.1 m |
| RF cavity | 2 | 2 | 4 |
| RF frequency | 60 MHz | 32.8 MHz | 32.8 MHz |

## REQUIREMENTS FOR AN ISOL DRIVER

As a result, commercial 70 MeV $H^-$ compact cyclotron was chosen for a RAON ISOL driver. The power of UCx target which is under development is 10 kW and will be 35 kW and 70 kW gradually in post-RISP. We will upgrade the beam current regarding the high-power target development.

As to the main issues, a carousel system with multiple foils and rapid foil exchange time is needed to continuously produce 70 MeV, 1 mA proton beam. The exhange of carousel system should be easy and done outside the cyclotron without opening the magnet to maintain the vacuum. The beam losses in a cyclotron is dominated by the vacuum dissociation. High vacuum level below $1\times10^{-7}$ Torr is required to minimize the beam losses in the level of less than 2 % inside the cyclotron. Additionally, a carbon blocks should be installed inside an extraction vacuum chamber to prevent activation of a vacuum chamber by neutralized H ions which is not fully stripped at the carbon foil.

The number of extraciton ports will be two, east-side port and west-side port. The east-side port will be used for Online test facility and multi-purpose facility. The west-side port will be dedicated to two ISOL targets. The beamline from the west-side port will be branched into two beamlines up to two target bunkers, repectively. The main components of the beamline are dipole magnets, quadrupole magnets, steering magnets, faraday cups, collimators, beam viewers, scanning system, neutron shutters, wire grids, and vacuum system. The wobbling or a raster scanning system will be placed in downstream of the beamline in a cyclotron vault for unform beam distribution on the ISOL target surface with a diameter of 50 mm. It is important to uniformly irradiate the beam on the UCx target surface to avoid local overheat. The uniform irradiation can be realized by various types of scanning systems. The neutron shutter next to the scanning system will be used to reduce the neutron leakage from the bunker when the beam is not used. Especially, a faraday cup, wire grid, and collimator before ISOL target in the bunker is required to monitor beam current and profile.

The RAON control system is based on EPICS (Experimental Physics and Industrial Control System). The main cyclotron control system should be integrated with the RAON EPICS. All the subsystems of the cyclotron should be controlled by PLC based hardware.

The main requirements for a RAON ISOL driver are summarized in Table 3.

## BUILDING LAYOUT

The design of the RAON facility is ongoing. The cyclotron system will be accommodated in ISOL building of RAON facility. The building consists of one basement and two stories. The cyclotron vault, the water cooling system, and two ISOL target bunkers are on basement (see Fig. 2). The power supply room for cyclotron system is on the 1st floor and the ISOL and cyclotron control room is on the 2nd floor.

The concrete shielding walls have been designed about 2.7 m thick to shield against 70 MeV neutrons to reduce the dose rate outside the shield wall to less than 5 µSv/h. The beam losses in a cyclotron were assumed to be 10 % of 1 mA.

## CONCLUSION

The maximum beam current of commercial 70 MeV cyclotrons is 750 µA. The UCx target for 70 kW beam power is also not designed, yet. RISP has decided to adopt the commercial 70 MeV $H^-$ compact cyclotron and to upgrade the beam current up to 1 mA as increasing the target capac-

ISBN 978-3-95450-167-0

Table 3: The Requirements for a RAON ISOL Driver

| **Parameters** | **Values** |
|---|---|
| Acceleration beam | $H^-$ |
| Extraction beam | $H^+$ |
| Extraction energy & stability | 35–70 MeV, <1% |
| Beam current & stability | ≥750 µA, <5% |
| No. of extraction ports | 2 |
| Extraction | Multiple Carbon stripper foils by carousel system |
| Continuous operating time | >300 hours |
| Beam size & uniformity on target | 50 mm, <5% with wobbling system |
| Horizontal beam emittance | <10π mm-mrad |
| Vertical beam emittance | <5π mm-mrad |
| Beam transport | Two beamlines up to ISOL targets |
| Vacuum pressure | $<1 \times 10^{-7}$ Torr |
| Control system | PLC based hardware integrated with RAON EPICS control system |

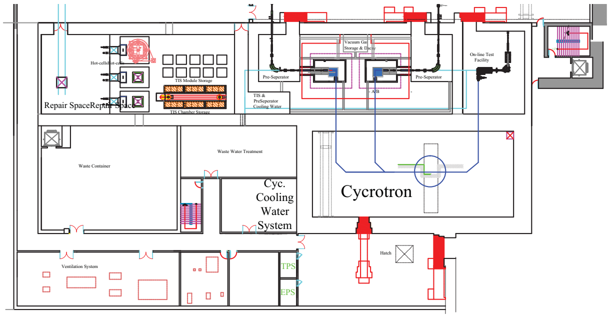

Figure 2: The basement floor plan of ISOL building. The cyclotron vault, the water cooling system room, and the ISOL bunkers are located on this level.

ity for the future work. Beamline configuration has not been fixed yet.

The project agenda is to complete the cyclotron system installation and get the first beam at the target by the end of 2019. The procurement process has just begun to meet the milestone. The bidding is expected to be held in September 2016 and the contract is expected to be made in this year-end.

## REFERENCES

[1] J. H. Kim, J. W. Kim, and Y. S. Kim "Thermal Distribution of a Carbon Foil Used to Extract a 30-MeV Proton Beam", *JKPS*, vol. 63, pp. 1296–1301, Oct. 2013.

[2] J. H. Kim *et al.*, "Investigation of Cyclotron Carbon Foil Lifetime in Relation to its Thickness", in *Proc. CYC2013*, paper TUPSH005, pp. 227–229.

[3] T. Zhang *et al.*, "Beam Loss by Lorentz Stripping and Vacuum Dissociation in a 100 MeV Compact $H^-$ Cyclotron", in *Proc. PAC'09*, Vancouver, BC, Canada, May 2009, paper FR5REP111, pp. 5035–5037.

[4] J. Martino, "ARRONAX, A High Intensity Cyclotron in Nantes", in *Proc. CYC2007*, Giardini-Naxos, Sicily, Italy, Oct. 2007, pp. 215–218.

[5] L. Medeiro-Romao *et al.*, "IBA C70 Cyclotron Development", in *Proc. CYC2007*, Giardini-Naxos, Sicily, Italy, Oct. 2007, pp. 54–56.

[6] G. Prete, A. Andrighetto, J. Esposito, P. Mastinu, and J. Wyss, "The SPES project: a second generation ISOL facility", *Physics Procedia*, vol. 26, pp. 274–283, 2012.

[7] M. Maggiore, A. Lombardi, and L. A. C. Piazza, "Status Report of the 70 MeV $H^-$ Cyclotron", INFN, LNL, Italy, Rep. 238, 2012.

[8] M. Maggiore *et al.*, "Status of SPES Facility for Acceleration of High Intensity Protons and Production of Exotic Beams", in *Proc. IPAC2014*, Dresden, Germany, June 2014, paper MOPRI079, pp. 791–793.

[9] L. Calabretta, T. Zhang, and A. Goto, "Review of the Cyclotron Subsystem Design Features for ISOL System", April 2014.

[10] L. Calabretta, "Review of the Comparison between Proton and Deuteron Cyclotrons", May 2015.

[11] A. Adelmann *et al.*, "Proposal for a High Power Deuteron Cyclotron at RISP", in *Proc. HIAT2015*, Yokohama, Japan, Sep. 2015, paper MOPA06, pp. 45–47.

ISBN 978-3-95450-167-0