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STATUS OF THE CYCLOTRON FACILITY AT RESEARCH CENTER FOR NUCLEAR PHYSICS

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Abstract

Research Center for Nuclear Physics (RCNP), Osaka University operates a K140 AVF cyclotron and a K400 ring cyclotron. We promote the nuclear physics, accelerator physics and related scientific fields using its unique beams. From 2018, the RCNP started the Research Center of Subatomic Sciences as the International Joint Usage/Research Center in Japan. It enables more efficient support for the researches using the resources of the RCNP facility. We have carried out the stable operation until Feb. 2019 when the 2 years of shutdown period starts for the upgrade works. We have been carrying out a program of the upgrade of the K140 AVF cyclotron. We aim at 10 times higher intensity for the proton beam than before and further stability of the operation. We also carried out the upgrade of the cyclotron building and related facilities to handle beams with higher intensity. The upgrade works are planned to be completed in the beginning of 2021. These upgrades are the most important programs to reinforce the function of the newly established center.

INTRODUCTION

Research Center for Nuclear Physics (RCNP), Osaka University operates a K140 AVF cyclotron which was completed in 1973 and a K400 ring cyclotron which was completed in 1992 and promotes the nuclear physics, accelerator physics, and related scientific fields since its foundation in 1971. Several kinds of the electron cyclotron resonance ion sources and a low energy beam transport system provide various ion beams including polarized proton and deuteron beams for injection to the K140 AVF cyclotron. The K140 AVF cyclotron have been used for providing medium energy beams to the experimental station and for injecting the beams to the K400 ring cyclotron. The K400 ring cyclotron accelerates protons up to 420 MeV at the maximum and other ions with their charge number Q and mass number A up to $400(Q/A)^2$ MeV. Precision of the beam energy is uniquely high ($\Delta E/E \sim 10^{-4}$) and it is taken advantage of in the precise measurement of the nuclear energy structures combined with the distortion matched beamline [1] and the world's most precise spectrometer Grand Raiden [2]. The proton beams with energy of 396 MeV is used for the production of secondary beams of muons as described in the later section and neutrons. The neutron beam with a broad energy spectrum is called as the white neutron beam which approximates the energy spectrum of cosmic ray neutrons on the ground level [3]. It is used for the test of the radiation-induced soft errors of semiconductor integrated circuits mainly by the industrial researchers. The middle energy beams are mainly used for the production of radioactive isotopes (RIs). We allied with 5 accelerator facilities in Japan and have provided short-lived RIs which are difficult to be commercially purchased. The accelerator building and the structure inside with the cyclotrons, spectrometers and the beam lines are shown in Fig. 1.

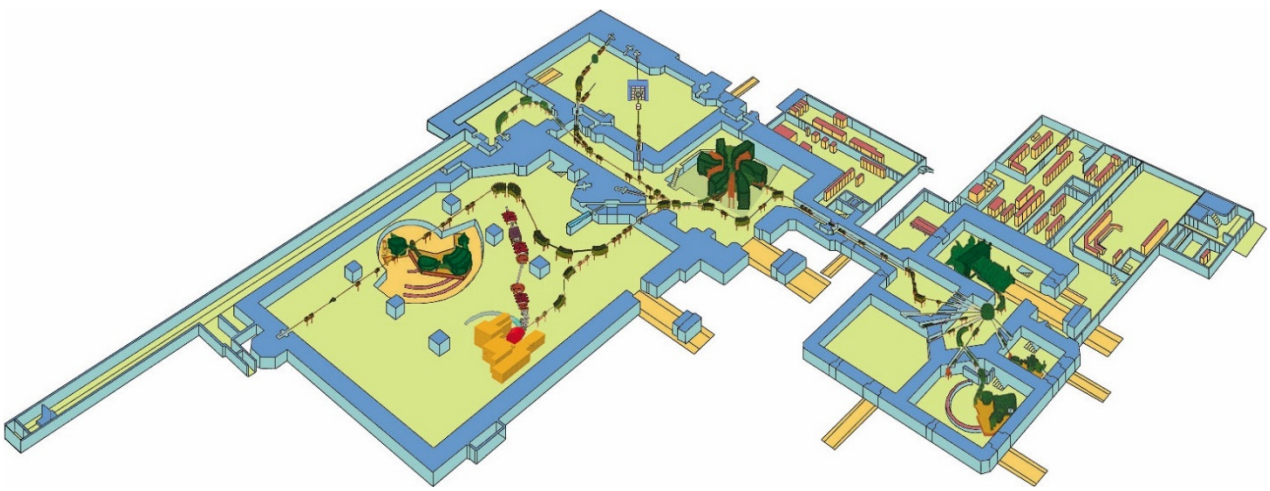

Figure 1: A birds-eye view of the RCNP cyclotron facility.

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OPERATION STATUS

The operation status is summarized in Fig. 2. The operation time of the cyclotron system was 5784 hours in year 2018. Main use of the beam is the experiments in the nuclear physics. Proton, deuteron and helium beams were used in physics experiment mainly at the WS beam course in combination with the Grand Raiden spectrometer. Polarized proton beam was used at the ENN beam course for the investigation of the three body nuclear force. Light to heavy ion beams were used at the EN course for the production of exotic nuclei to study their structures. The next frequent use was the RI production. Alpha beam was mainly used for the production of ^{211}At which is one of the nuclides attracting interest in Japan as one of the alpha emitter to be used in the targeted alpha therapy of the cancers. The unscheduled shutdown was 111 hours. The usual causes of the troubles were water leaks from the plastic tubes used for the electric insulation and faults of electric power lines. Times needed for the recovery from these troubles were a few hours per trouble at the longest but we have to try to reduce the frequency of their occurrence. The troubles with the power lines may be resolved by the renovation of the power systems in the upgrade works of the cyclotron facilities. The troubles with the water leakage from the plastic tubes should be investigated and we have to make some countermeasures against them. We finished the machine operation on 11 Feb. 2019 for the upgrade works. The machine operation is scheduled to start from the beginning of 2021 after the completion of the upgrade of the K140 AVF cyclotron.

MUON BEAMLINE

We constructed a new continuous (DC) muon beamlines, MuSIC (MUon Science Innovative Channel) which consists of a superconducting solenoid systems for the pion capture and the muon transport [4, 5]. A 396 MeV proton beam with an intensity of 1.1 μA is impinging on a graphite target at the frequency of 16.8 MHz. Produced charged pions are captured by the pion capture magnet with B = 3.5 T and the muons emitted from the decay of the pions are transported to the beam line. The intensity of the negative muon is ~ 10^5 counts per second and that of the positive muon is ~ 10^6 counts per second. Its construction and commissioning were finished in 2017 and it have been used for nuclear physics experiments to investigate the three body nuclear force and muonic nuclear transmutaion, material analysis with specific muonic X-rays, and the estimation of the soft error rates of the integrated circuits induced by muons. The number of users have been constantly increased and many important results have been reported from the experiments.

UPGRADE OF THE RCNP FACILITIES

The upgrade program of the K140 AVF cyclotron and the RCNP facility was planned for the reinforcement of the function of the RCNP as the center to support the communities of researchers. Increasing the primary beam intensity

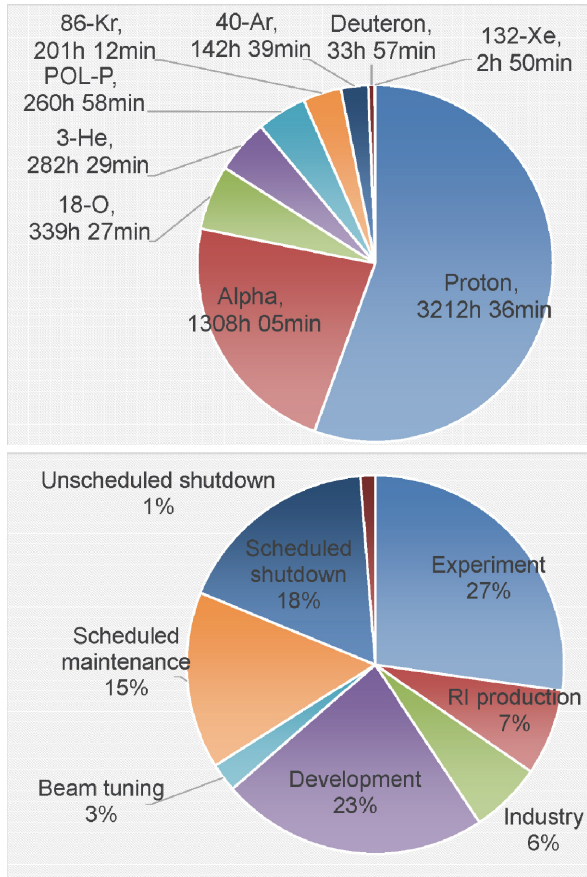

Figure 2: Summary of the beam time with respect to ion species (upper panel), with respect to uses (lower panel).

will increase the amount of produced RIs, the intensities of the secondary beams and the beam quality needed for the precise measurement. In this upgrade, we estimate that at least 10 times higher beam intensity will be achieved.

The RCNP started the Research Center of Subatomic Sciences as the International Joint Usage/Research Center in Japan in 2018 financially supported by Japanese Ministry of Education, Culture, Sports, Science and Technology because of the high reputation to the efforts which the RCNP has been spent to support the researches and the communities of the researchers. In order to promote the activity of the center, the upgrade of the facility is important. The upgrade consists of three elements and they are described in the following of this section.

Ion Sources and the Low Energy Beam Transport

In order to increase the intensity of the accelerated beams, increasing the brightness of the ion sources is inevitable. We are developing a high intensity ECR ion source for proton and light ions referring to the IFMIF type ion source [6, 7]. We also prepared a duoplasmatron ion source which enables substantially low emittance and high intensity. We plan to increase the extraction voltage of all the ion sources from 10 – 15 kV to at least 50 kV and design a low energy beam transport to treat the higher energy ion beams. Reducing the emittance to match the acceptance of

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the K140 AVF cyclotron will increase the beam amount injected into the cyclotron.

Upgrade of the K140 AVF Cyclotron

The beam with higher intensity may more strongly affected by the space charge effect. It is better to finish acceleration in shorter time before the beam spreads by the repulsive force. We plan to replace the current single Dee electrodes of the K140 AVF cyclotron to double Dee electrodes covering ~ 90 degrees. With harmonic = 2 acceleration, a beam bunch can be accelerated 4 times in one turn and thus the number of turns needed to reach the maximum energy. The RF system consisting resonators, couplers, amplifiers are newly designed to match this replace of Dee electrodes. Deflectors and gradient correctors are also designed to deal with the change of beam trajectory. Inflector electrodes and phase slits have to be newly designed for accepting 50 kV accelerated ions. All the probes are newly designed to handle the higher power dissipated by the more intense beams. The old trim coils and valley coils are replaced to new ones. The vacuum chamber and pumping system are also renewed. Thus the K140 AVF cyclotron is almost completely renewed. Only the main coils, yokes, and poles are to be reused.

Readers are referred to the reference [8] for the detail of the upgrade of the K140 AVF Cyclotron.

Upgrade of the Cyclotron Buildings and Facilities

In order to handle more intense beam, the apparatuses are also renewed:

1. Thicker shielding wall, especially surrounding the beam line from the AVF cyclotron to the ring cyclotron.
2. The cooling towers for higher cooling capacity.
3. The RI drainage system to handle larger radioactivity.

Adding to them, old apparatuses, floors, roofs are also renovated. The construction work started from the April 2019 and planned to be completed in March 2020.

We also plan to renovate the white neutron beam line. The radiation shielding on the ceiling is added to handle the higher radiation. The diameter of the hole for the neutron beam duct is enlarged to enable the neutron beam with larger diameter so that larger area of the printed board is irradiated at one time. This renovation will serve for more efficient use of the beam time.

SUMMARY

The RCNP operates AVF cyclotrons that are more than 40 years old and ring cyclotrons that are more than 20 years old with unchanged stability in operation. We constructed the new beam line for DC muons and made steady progress in nuclear physics, nuclear chemistry, nuclear medicine and information science. From this year, the upgrade works of the K140 AVF cyclotron has been started. And the renovation of the buildings and the apparatuses has started for handling of beams with increased intensity and for repairing or replacing the aged apparatuses which are nearly out of order. Through these upgrade and renovation, we aim at improving the functions of research center in related fields and further development.

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