"Restart of the accelerator facility"

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The upgrade work of the accelerator facility of Research Center for Nuclear Physics has begun in 2019 to renovate the AVF cyclotron and to improve the performance of the accelerator and the functionality of the RCNP as the Center for the International Joint Usage and Research. The main purpose of these renovations and upgrades is to increase the current of the AVF cyclotron to meet the increasing demand for more intense secondary particle beams and for the mass production of RIs. The increased beam intensity can offer the room for a cut-off to provide the high precision beam for the precise nuclear physics.

After the approval of the use of the radiation generator by the Nuclear Regulation Agency Japan in March 2022, we have carried out the beam commissioning of the AVF cyclotron for the inspection of the facility related to the use of the radiation generator. The condition for passing the inspection was proving the increased radiation shielding capacity by the modification of the structure of the shielding walls by stopping the 65 MeV protons with sufficient current on the slit SV8-C. In the renovation work, the concrete thickness of the walls and ceilings of N experiment hall, where SV8-C is located, was increased to strengthen the shielding capacity in response to the increased intensity of the beam from the accelerator. We started transporting the 50 keV proton beams from the modified NEOMAFIOS which originally extracted the positive ions with 15 kV acceleration voltage on 22 March 2022. We confirmed the arrival of protons to the inflector electrodes on 24 March. We measured the beam current of ~ 2 μA at the radius of 200 mm with the main probe of the AVF cyclotron on 31 March. It meant that the protons were successfully injected into the AVF cyclotron and accelerated to a few MeV (20 – 30 turns). After substantial effort by the SAS operators and the RCNP staffs, we confirmed the extracted proton beam from the AVF cyclotron on 21 April. The inspection was carried out on 10 May with 0.11 μA proton beams stopped on SV8-C. The current was 20% of the maximum applied current. The equivalent dose of the neutron and gamma-rays measured were significantly lower than the legal regulation. After passing the inspection on 11 May, we started supplying the beam for the users mainly aiming at the commissioning of their experimental apparatuses and the educational use. We also started commissioning of the RF system for the acceleration of 28.5 MeV $^{4}He^{2+}$ from the end of May. The acceleration and extraction of $^{4}He^{2+}$ was succeeded by the middle of June. The $^{4}He^{2+}$ was first supplied to the new target irradiation terminal at F-course in W experimental hall to produce ^{211}At on the end of July.

We had started the commissioning of the vacuum system, RF system, and cooling water system of the ring cyclotron from the beginning of FY2022 and found some troubles in them. After fixing them, some of them were very severe trouble and took a few months to procure spare parts and to repair them, we started the beam commissioning of the ring cyclotron from the beginning of October. We successfully accelerated proton beams of 65 MeV supplied from the AVF cyclotron to 392 MeV by 4 October. The 392 MeV ~1 μA proton beams were transported to the WN course and the white neutron beams were successfully supplied. The beam time for the white neutron irradiation to semiconductor devices by private companies were assigned from 27 November to 5 December. During this period, the proton beams were stably supplied without any severe trouble. We have obtained the comments by some users of the WN course that the single event upset rate was similar to the ones obtained with the WN course before the upgrade of the AVF cyclotron. We tried to measure the energy spectrum and the profile of the while neutron beam. However, due to the troubles in the beam pulsing and the severe background from the highly activated tungsten target, the measurements ended in failure. We would take this failure as a lesson and try to measure the neutron beam properties in the next chance. We also supplied the 392 MeV proton beam to WS course for the commissioning of the Grand Raiden. In the test of the high-resolution achromatic beam transport mode, the energy spread of the proton beam was measured with the Grand Raiden and 180 keV (FWHM) was obtained for 392 MeV proton beam. The goal is 100 keV (FWHM) and we still need to develop the high-resolution beam transport parameters.

In summary, we have restarted the AVF cyclotron and ring cyclotron in 2022. The proton and $^{4}He^{2+}$ beams were supplied for users who have longed for the restart of the beam use. Currently available type of beams is listed in Table 1. These are a very part of the types of beams available before the upgrade of the AVF cyclotron. Though the financial situation is quite severe mainly due to the soaring electricity bills, we would like to manage the time for the development of new types of beams and supply them to the users.

Table 1: List of currently available beam and after the AVF cyclotron upgrade.

Ion	H^{+}	H^{+}	$^{4}He^{2+}$
Energy (MeV)	65	392	28.5
Max. Current (eμA)	1.1	1.1	4
Transported Beam Course	WS, ES, N0	WN, WS	F, WS, EN