PRESENT STATUS OF CYCLOTRONS (NIRS-930, HM-18) AT NIRS

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Abstract

The cyclotron facility at National Institute of Radiological Science (NIRS) consists of a NIRS-930 cyclotron (Thomson-CSF AVF-930, Kb=110 MeV and Kf=90 MeV) and a small cyclotron HM-18(Sumitomo-Heavy- Industry HM-18, K=20 MeV). The NIRS-930 has been used for production of short-lived radio-pharmaceuticals for Positron Emission Tomography (PET), research of physics, developments of particle detectors in space, and so on. The orbit of a beam in the NIRS-930 cyclotron was simulated with integrated approach for modelling of the cyclotron, including calculation of electromagnetic fields of the structural elements. And some improvements such as installation of extracted beam probe, a beam attenuator and a beam viewer in an injection beam line, were performed in the NIRS-930. The HM-18 has been used for production of short-lived radio-pharmaceuticals for PET. It provides us accelerated H^- and D^- ions at fixed energies of 18 and 9 MeV, respectively. In order to improve the isochronisms, a phase probe has been newly installed in the HM-18. Operational status of the cyclotron facilities and their improvements are to be presented in this report.

INTRODUCTION

There are two cyclotrons, the NIRS-930 and the HM-18, in the cyclotron facility at the NIRS (Figure 1). These two cyclotrons are installed in the same room. The NIRS-930 (Km=110 MeV, Kf=90 MeV) was installed for the main purpose of clinical trial of radio-therapy with fast neutron in 1974. After that, the main purpose of the NIRS-930 changed to proton radiotherapy and has shifted to RI manufacture for molecular imaging. The HM-18(K=20) cyclotron is a negative-ion accelerator that was purchased from Sumitomo Heavy Industry, Ltd. The HM-18 has been operating routinely to produce short-lived radio-pharmaceuticals for PET in conjunction with a heavy ion therapy at HIMAC (Heavy Ion Medical Accelerator in Chiba) since 1994[1].

OPERATION

The NIRS-930 and the HM-18 are operated only during the daytime (9:00-17:00) of weekday, and the NIRS-930 is operated twice per month also on Saturday.

For maintenance, there are three weeks and two weeks shutdowns in summer and spring, respectively. The annual operation time last year of the NIRS-930 is shown in Table.1. The planned operation time was 1648 h, which is multiplication of the days of a scheduled experiment by 8 hours. On the other hand, actual operation time was 1936 h at NIRS-930. The half of the operation time of experiment was used for RI production for radiopharmaceutical products including ^{11}C, ^{18}F, ^{28}Mg, ^{64}Cu, ^{62}Zn, ^{124}I. The other purposes are nuclear and atomic physics experiments, a radiation damage tests with charge beam time fee, studies on radiation damage of material and an electronic device by particle beam or fast neutron, biological experiments, and studies on radiation dosimetries for space radiation. Unscheduled beam stop time by failure was 11 hour; it was 1.8% of total operation time, which was composed of failures in vacuum system, vacuum tube in amplifier of radio frequency system, a current meter for beam monitoring, and human error.

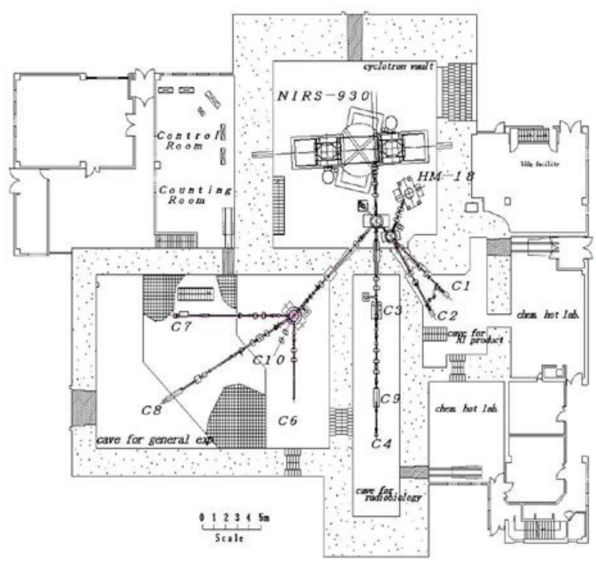

Figure 1: Layout of NIRS cyclotron facility.

Table 1: Annual Operation Time of the NIRS-930 (2012)

Planned time of operation		**1648 h**
Operation time	**Total**	**1936 h**
1. Experiment		1350 h
2. Tuning operation and machine studies		552 h
3. Beam time cancel by operation side *		24 h
4. Unscheduled beam stop by failure		11 h
1 Experiment summary		
RI productions		686 h
Nuclear and atomic physics experiments		304 h
Radiation damage tests (with charge beam time fee)		176 h
Studies on radiation damaged		91 h
Biological experiments		64 h
Studies on radiation dosimeters		29 h

4. Unscheduled beam stop by failure	
Vacuum system	5 h
Radio frequency system (Vacuum tube)	3 h
Beam monitor	1 h
Human error	2 h
Beam stop time / Operation time	1.8%

(*Beam intensity was not able to fill a demand.)

The annual operation time last year of the HM-18 is shown in Table 2. The HM-18 has been operated only for RI production of radiopharmaceutical products including ^{11}C, ^{18}F, ^{15}O. The planed operation time for RI production was 1548 hours. The total operation time was 1823 hour and 1748 hours of them were RI productions. Almost total operation time was used with proton for RI production such as ^{11}C, ^{18}F; on the other hand, only 10 hours were used with deuteron for RI production of ^{15}O. Unscheduled beam stop by failure time was only 5 hours, which was 0.3% of total operation times. The content of failure consists of damage of stripping foil (carbon 100 μg/cm^2). Another reason was repairs of NIRS-930, because two cyclotrons locate in the same room.

Table 2: Annual Operation Time of the HM-18 (2012)

Planned operation time for RI productions		**1548 h**
Operation time	**Total**	**1823 h**
1. Protons used RI productions		1748 h
2. Deuterons used RI productions		20 h
3. Tuning operation and machine studies		50 h
4. Unscheduled beam stop by failure		5 h
4. Unscheduled beam stop by failure		
Stripping foil		3 h
Other (Repairs of NIRS-930)*		2 h
Beam stop time / Operation time		0.3%

(*Since the NIRS-930 is in the same room.)

IMPROVEMENT

Phase Probe for NIRS-930

The NIRS-930 has twelve trim coils for generation of the isochronous fields. Until recently, currents of the twelve trim coils had been adjusted only by monitoring the output beam intensity. The isochronous field was indefinite because the beam phase was not able to be measured. Therefore, a phase probe has been newly installed in order to exactly produce the isochronous fields.

The phase probe has ten pickup electrodes. The beam pickup signal from each electrode is compared with the one from the innermost electrode by oscilloscope.

The trim coil currents were optimized based on results of beam phase measurements for the various energy and ion beam. Figure 2 shows phase excursion of 30 MeV protons. Vertical axis is beam phase. Horizontal axis is phase probe number.

The blue circles are beam phase before optimization of trim coil currents. It was used for previous operation. The red squares are beam phase after optimization of trim coil currents. The phase excursion could be reduced within 5 degree.

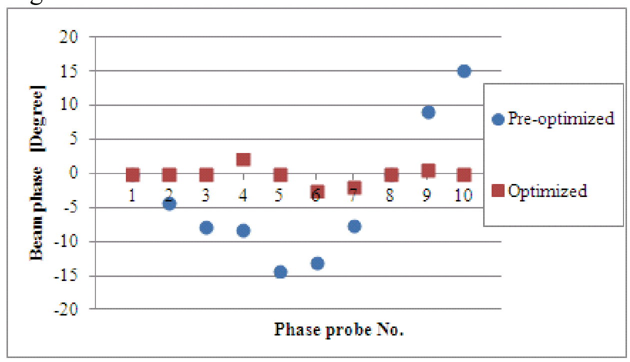

Figure 2: Phase excursion of 30 MeV protons.

Beam Simulation of NIRS-930

The behaviours of beam in the NIRS-930 is simulated based on electric and magnetic field distribution. Beam is simulated by the program complex SNOP [2]. Electric and magnetic field distribution was calculated by the Opera 3D[3] for input data of the SNOP.

The calculated beam phase and particle losses inside the cyclotron also agree with the results of experimental measurement under beam operation of 30 MeV protons[4]. The simulations of the other particles and the different energies are to be performed in due time.

Beam Injection Line for NIRS-930

Layout of injection line of NIRS-930 was shown in Figure 3. The injection line had been improved for daily operation. First, a beam attenuator was installed for beam intensity control (Figure 3. label "A"). It has two attenuation meshes which have attenuation factors of 1/10 and 1/100. Next, three beam viewers and two steering magnets were installed to improve transmission efficiency. The result of beam adjustment using those beam viewers and those steering magnets is shown in Table3. The transmission efficiency to FCN3 located in a downstream of the quadrupole electrodes form FCN2 was improved from 68% to 76%. And the efficiency from FCN4 to an inflector was improved from 78% to 90%.

Moreover, the saw-toothed-wave beam buncher is developed for increasing beam current. The new electrode was a single gap type, and dependence of bunching efficiency on the position of the beam buncher was measured under the operation by sine-wave [5]. The new electrode was installed at the distance of 1.53 m from inflector (Figure 3. Label "B"). Next, the signal control and a power amplifier system are due to be constructed.

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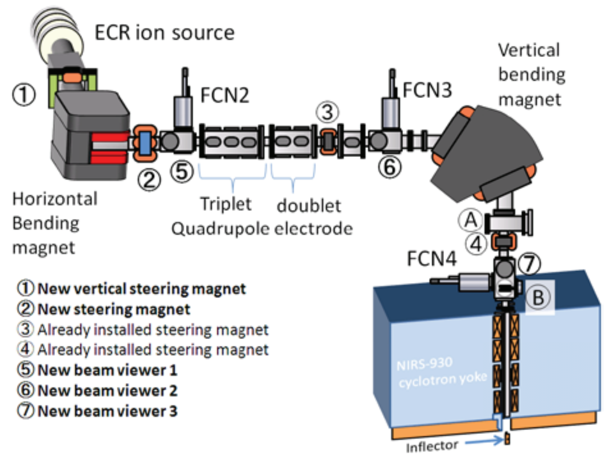

Figure 3: Layout of injection line for NIRS-930.

Table 3: Beam Current and Efficiency of Axial Injection Line at NIRS-930 in 30 MeV Proton Operation

Beam current [μA]	**FCN2**	**FCN3**	**FCN4**	**Inflector**
Pre-Adjustment	217	148 (68%)	134 (91%)	104 (78%)
Adjusted	218	166 (76%)	155 (93%)	139 (90%)

(Transmission efficiency)

Phase Probe for HM-18

In order to exactly produce the isochronous fields, a phase probe has been newly installed in the HM-18[6]. This phase probe has simple structure and easily installed in the cyclotron. The beam phase excursion was measured at HM-18, and improved by adjustment to the magnetic field (Figure 4). However, the beam intensity decreased. This might be caused due to such a situations the position of an internal ion source and a puller electrode were not optimized.

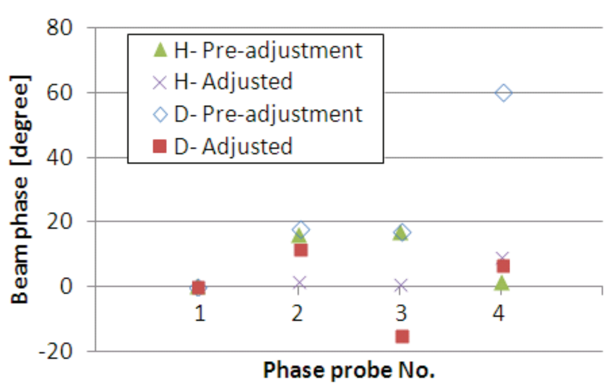

Figure 4: Phase excursion at HM-18 (18 MeV H^-, 9 MeV D^-).

Radial Probe for Measurement of Extracted Beam from NIRS-930

The extracted beam from NIRS-930 passes through the electric deflector, the magnetic channel, and gradient corrector, and goes to downstream beam transport line.

Until now, beam current was not able to be measured from entrance of electric deflector to downstream beam transport line. Therefore, a radial probe was newly installed for measurement of beam current after passing through the magnetic channel. This probe is able to move to position between 1070mm and 1170 mm from the cyclotron center.

Figure 5 shows the beam distribution of 30 MeV protons by measurement used this radial probe. Vertical axis is difference of beam current by moving (one-step distance is 1 mm) radial probe. Horizontal axis is position of radial probe from cyclotron center. The width of beam was 12 mm, and the center position of beam was 1128 mm.

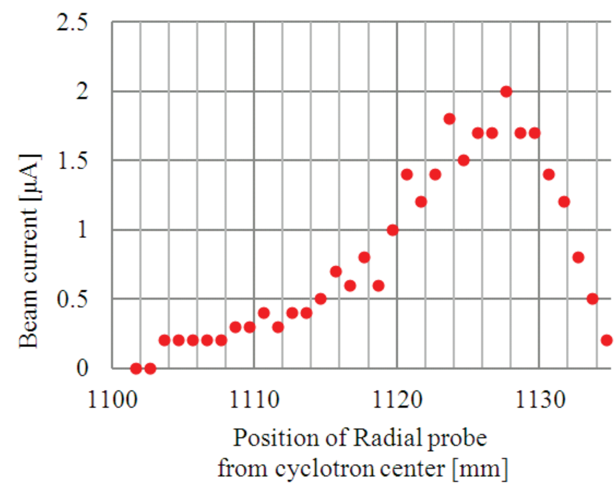

Figure 5: Beam profile by radial probe (30 MeV protons).

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