PRESENT OPERATIONAL STATUS OF NIRS CYCLOTRONS (AVF930, HM18)

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Abstract

Since Japanese government launched a new program of the "Molecular Imaging Research Program" in 2005, the NIRS AVF930 cyclotron has been mainly operated to produce radio-isotopes together with a small cyclotron (HM18) for PET imaging. There are also machine operations of the AVF930 for physical experiments and tests of radiation damage on electric devices. To carry out cyclotron operations for these purposes, some improvements have been done in the facility. In this report, we will present recent operational status of the NIRS cyclotron facility (AVF930, HM18), and its improvement points.

INTRODUCTION

In 1974, operation of the NIRS (National Institute of Radiological Sciences) isochronous cyclotron (AVF930) was started, which was for clinical trial of radio-therapy with fast neutron. Besides this main purpose, production of short-lived radio-nuclides and proton radio-therapy were intended to study. In June 1994, because a new facility of heavy ion accelerator complex of the HIMAC (Heavy Ion Medical Accelerator in Chiba) has started its operation for carbon ion radio-therapy, the fast neutron therapy with the AVF930 had been terminated. In conjunction with start of the HIMAC operation, a new small cyclotron (HM-18 by Sumitomo heavy industry) was installed just beside the AVF-930 as shown in Fig. 1. With the HM18, short-lived radio-isotopes of ^{11}C and ^{18}F are produced to get radio-pharmaceuticals for PET diagnosis before and after carbon ion radio-therapy in the HIMAC. Corresponding this change of situation, the utilization of the AVF-930 also has been shifted to general experiments and radio-isotope productions except for above common isotopes such as ^{11}C, ^{13}N, ^{15}O and ^{18}F. The axial injection system has been installed to provide various kinds of heavy-ions for general experiments, where an ECR ion source with permanent magnets has been equipped. With this ECR ion source, we can supply not only proton but also light ions for cyclotron user.

In 2005, MEXT (Ministry of Education, Culture, Sports and Technology) of Japan launched a new program called the "Molecular Imaging Research Program", and the NIRS was selected as one of centre in Japan. One purpose of this program is the application of imaging technology with PET by use of radio-pharmaceuticals with super-high specific activity. For this purpose, an old RF system of the AVF930 cyclotron has been replaced to a new one for its stable operation[1].

For production of common short-lived radio-isotopes such as ^{11}C, ^{13}N, ^{15}O and ^{18}F, the target stations of C1 and C2 can be used, where the beams are provided from both cyclotrons, but not simultaneously (see Fig. 1). With the AVF930 cyclotron, beam will be transported to target stations of C4 and C9, where radio-nuclides with longer life times will be produced. Physical experiments will be arranged in the target stations of C3, C6, C8, and C10 according its requirements.

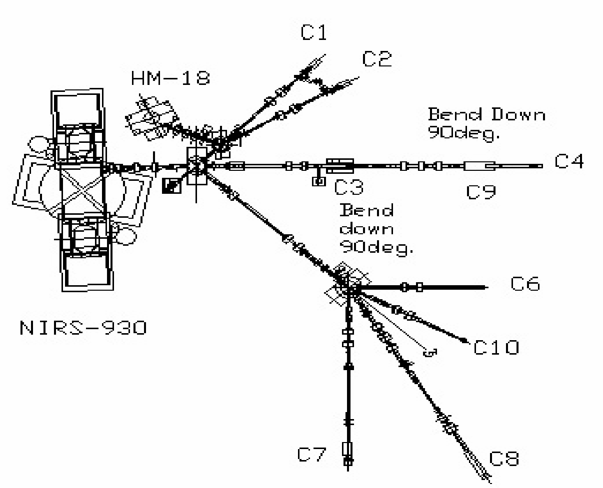

Figure 1: Layout of cyclotrons and beam lines.

OPERATIONS

In annual schedule of the AVF930 and the HM18 cyclotrons operations, there are two maintenance periods, which are planed in March and August with two or three weeks. Weekly maintenance is scheduled in Monday with full and half day every two weeks. Though the main purpose of the AVF930 cyclotron is RI production, there is about one day for general experiments in a week. Daily operations of the AVF930 and the HM18 cyclotrons will start at 9 am until evening. With those operational conditions, annual operation times in recent several years are shown in Fig. 2. Last year, there was no serious break-down in the AVF930 and the HM18, and both cyclotrons could be operated about 1500 hours as scheduled. In 2005 and 2006, operation times were short, which was due to renewal of an acceleration system of the AVF930, where D-electrodes, resonators, RF amplifiers, and control systems have been replaced[1]. With this renewal, operation of the AVF930 has become stable to supply beam for RI production.

In a control system of HM18, a PC9801 computer of NEC was used to control the devices in the cyclotron by use of UDC's (Unit Device Control), which was a control system made by Sumitomo Heavy Industry. These system was used since 1994, and becoming difficult to repair due to its non-compatibilities of the control computer and the UDC's. Considering these situations, we have replaced the control system of the HM18 together with power supplies and stepping motors in the end of 2007 financial year. In the new system, a personal computer with windows XP is used in a man-machine interface, and PLC's are used to control the each device in the HM18 cyclotron.

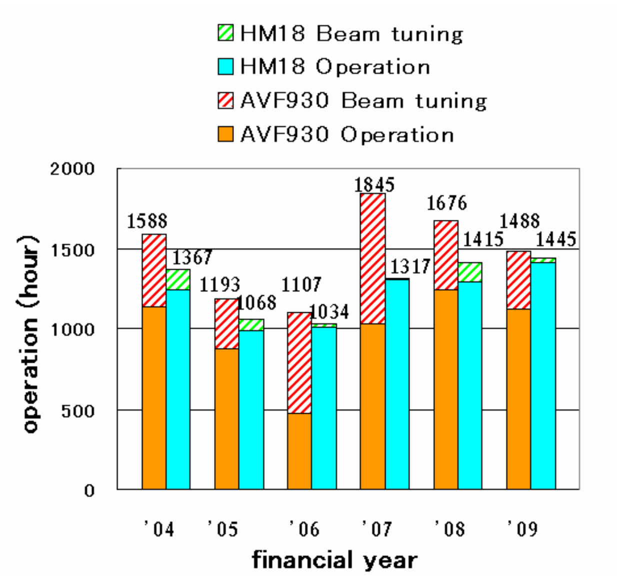

Figure 2: Operation time of the AVF930, and the HM18.

Experimental Fields with the AVF930

Since 2006, largest fraction of the AVF930 machine time was used for RI productions to study PET diagnosis with produced radio-pharmaceuticals. As shown in Table 1, its operation occupied about 37% of AVF930 machine time. Radiation dosimeter developments, physical experiment, radiation damage tests with neutron, biological experiments, and radiation damage tests with proton were also studied as in table 1. If there is requirement for machine operation such as new particle or new energy value, we will test the required operational condition that is classified as "Tuning operation and machine developments".

Beam Energy and Particles in the AVF930 Operation

Accelerated particles and energies in the AVF930 operation are summarized as in Table 2. For the RI production, proton was used, where lower energy proton (lower than 40MeV) was usually required. If there were requirements for higher beam current, we have accelerated H_2^+ beam to increase beam current. For the radiation damage tests, proton energy of 70 MeV was usually selected. In the case of damage test with neutron, deuteron was accelerated up to 30 MeV, and Be target in C3 course was used to generate neutron. Including other experiments, used AVF930 operation times of each energy and particle are summarized as in Table 2.

Table 1: AVF930 operation times for classified fields

RI productions for radiopharamaceutical	547.8h(36.8%)
Studies on radiation dosimeters	329.9h(22.2%)
Physical experiments	124.0h(8.3%)
Studies on radiation damage with neutron	30.4h(2.0%)
Biological experiments	14.8h(1.0%)
Radiation damage tests (Pay experiments)	78.3h(5.3%)
Tuning operation and machine developments	362,3h(24.4%)
Total	1487.5h

Table 2: Particles and energies of AVF930 operation

proton		carbon (6+)		other particles	
energy (MeV)	operation (h)	energy (MeV)	operation (h)	energy (MeV)	operation (h)
80.0	11.5	180.0*	4.0	H_2^+ 27.0	288.9
70.0	273.9	156.0*	3.5	H_2^+ 28.0	166.0
50.0	9.0	144.0	28.0		
40.0	34.3	120.0	24.5	d^+ 30.0	39.6
30.0	163.9	72.0	173.5		
18.0	65.3	48.0	32.8	α 40.0	10.5
16.0	23.0				
12.0	74.0			$^{13}C^{4+}$ 104.0	24.3
10.0	26.0			$^{13}C^{4+}$ 143.0	11.0
	680.9		266.3		540.3
				total time (h)	1487.5

『*』without beam extraction

IMPROVEMENTS

Experimental Course of C8

Beam course of C8 is utilized for experiments that require laterally uniform beam distribution. To fulfil this requirement, wobbler magnets are equipped at 3m upstream of target point. These wobbler magnets can rotate beam direction with 12Hz, and we can obtain uniform beam distribution at the target point in combination with aluminium scatterer of 0.18mm thick at upstream of wobbler magnets. Beam uniformity was checked in the experiments with 70MeV proton, and the obtained uniformity of ±5% in the region of ±4cm in lateral direction. With this uniformity of beam distribution, detector tests, biological experiments, and radiation damage tests of electronics have been performed. To control exposure dose more accurately, a beam monitor and a quick shutter have been equipped at the end of beam line and upstream of wobbler magnets, respectively. This quick shutter can be closed manually, and also with a TTL gate signal. A closing speed was estimate with extra beam quantity after the closing gate signal, and a closing time of 200ms was obtained with this measurement[2].

Though experiments have been performed well, high energy operation has problem recently in a magnetic channel. We could not excite the magnet with required field strength due to increasing cooling water temperature. Replacement to a new magnetic channel[3] is planned in this financial year.

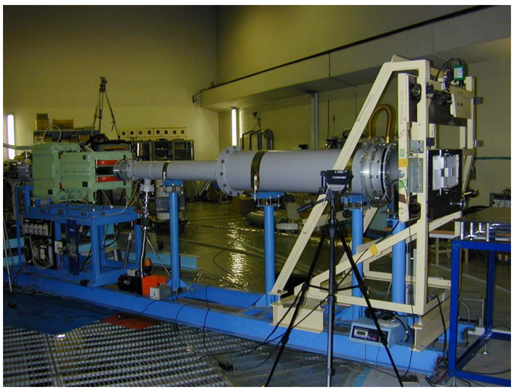

Figure 3: Beam course of C8 for physical experiments with wobbler magnets and scatterer to obtain uniform lateral distribution.

Horizontal Irradiation Course of C4.

The C4 course can be used for metal target irradiation to produce RI, where a robotic system and a target transport system to a hot cell are equipped to produce radio-pharmaceuticals. With this irradiation course, collaborative studies on the usefulness of [^{62}Cu]ATSM for tumor hypoxia imaging had been performed among NIRS, and other three laboratories from 2007 until summer of 2009. Produced ^{62}Zn/^{62}Cu generator, a source of ^{62}Cu for [^{62}Cu]ATSM labelling, has been produced in NIRS and delivered to collaborative laboratories. Production of ^{62}Zn can be achieved by the irradiation with 30 MeV proton beams on natural Cu target via the ^{nat}Cu(p,xn)^{62}Zn reaction. This collaborative study is planed to restart at the end of 2010, and several improvements were taken in this course. First one is installation of quadrupole and stirring magnets (see Figure 4) at the end of this C4 course to adjust beam shape and center easily. Second one is replacement to new target port where a collimator divided in four parts will be equipped to get information of beam position during irradiation. Target cooling is also reinforced with increase of cooling water pressure and good thermal contact by an aluminium target holder.

Other Improvements.

Increase of beam intensity will be desired in several cases. For example, in the operation for ^{62}Zn/^{62}Cu generator production, required irradiation time is 10h (9:00-19:00) with beam intensity of 20μA to use ^{62}Cu-ATSM in four laboratories. After irradiation, chemical process to produce ^{62}Zn/^{62}Cu generator, including purification of ^{62}Zn, filling in generator column and quality control must be performed to ship produced generators at 24:00. If we can supply higher beam intensity, operation schedule of the cyclotron become flexible and easy to manage with shorter irradiation time. For this purpose, a single gap buncher with higher harmonic waves in an injection line is planned to install[4]. With this new buncher, we expect better bunching ratio and extraction efficiency, with which we can increase the beam current on the target.

Figure 4: Horizontal irradiation course of C4 without target station.

To reduce residual radiation level in the cyclotron facility, we have replaced a beam shutter that is made of a copper plate. New one is a Faraday cup that has a cooled graphite of 10mm thick and a cupper plate of 0.2mm thick at entrance. With this structure, proton of lower energy than 47 MeV can be stopped in the graphite. This choice of the graphite thickness is practical because high intensity proton operation is usually with lower energy than 40MeV.

Replacement of a control system for the injection line is undergoing, where a PLC will be used instead of current potentiometers.

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