IMPROVEMENTS AND APPLICATIONS AT NIRS CYCLOTRON FACILITY

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Abstract

The NIRS-Chiba isochronous cyclotron has been working in routinely, and providing the stable beams for bio-medical studies and various kind of related experiments since 1975. The clinical trail of eye melanoma has been under continued. Recently two new beam lines were constructed in order to carry out the bio-physical study , and to produce the long-lived R.I.s for SPECT. Some progressive improvements, such as updating the magnetic-channel and development of a floating septum system, were performed for stable operation of the cyclotron. A brief review of the current status of the cyclotron and typical application of latest experiments in the various fields are described.

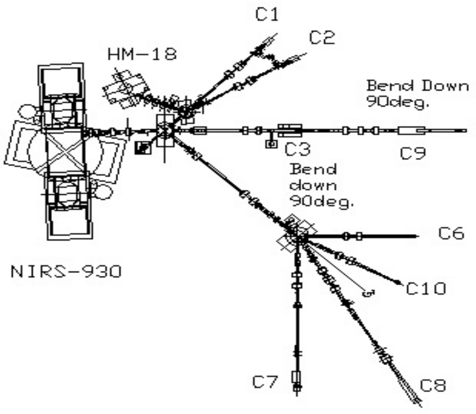

Fig.1 Floor plan of NIRS cyclotron facility in March, 2000.

1. INTRODUCTION

The NIRS cyclotron facility constitutes of a large isochronous-cyclotron[1] (NIRS-930), a small cyclotron (HM-18) and nine experimental beam lines. In Fig.1 the present layout of the cyclotron facility is shown. The NIRS-930 has been used mainly for clinical trials of proton therapy such as eye melanoma, production of the short-lived radio-nuclides, research of bio-physics, development of particle detectors for space application and so on. The small HM-18, constructed in 1994, has been operating routinely to product short-lived radio-pharmaceuticals for PET in conjunction with a heavy ion therapy in HIMAC[2] (Heavy Ion Medical Accelerator in Chiba).

Two new beam lines C10 and C4 were constructed during the past two years. The line C10, which was installed in the general-purpose experimental cave, is used for basic study of bio-physics as described in section 3.3. The line C4 was designed and constructed for development of long-lived radio-nuclides for SPECT with high current proton beam of 65 MeV. It will be started in this summer. The high flux neutron cave C3, which had been used for fast neutron therapy, was modified in order to study biological effects by an accidental neutron exposure to humans.

Operation of those two cyclotrons is scheduled in the daytime from Monday afternoon to Friday except the regular maintenance time during two weeks of March and August annually. Table 1 shows the statistics of beam time distributions among the research fields in 2000.

The following, some progressive improvements in the NIRS-930 and current status of the latest experiments in the field of applications are presented.

Table 1. The distribution of beam time among research field.

1.	Clinical trial of eye melanoma :	88.8 h	(6.8 %)
2.	Production and development of : short-lived radio-nuclides	215.8 h	(16.6 %)
3.	Studies of particle detectors : and radiation dosimetry	450.2 h	(34.6 %)
4.	Basic research of radiological : experiments	7.5 h	(0.6 %)
5.	Related Experiments :	207.3 h	(15.9 %)
6.	Preparing beam :	331.9 h	(25.5 %)
	Total :	1301.5 h	

C1, C2 : Production and development of short-lived R.I.s,
C3 : Biological studies with high flux neutron beam
C4 : Production of R.I.s for SPECT,
C6 : Development of particle detectors and beam monitors,
C7 : Radiobiological experiments with heavy ions,

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C8 : Studies of radiation dosimetry,
C9 : Proton therapy for eye melanoma,
C10 : Experiments of biophysics.

2. IMPROVEMENTS

The NIRS-930 cyclotron having K=110 consists of four sectors and two Dees(86 deg.) connected to moving panel type of rf-cavities. The frequency range of 10.7-21 MHz covers 1st and 2nd harmonic in the acceleration modes. The stable beams of proton with energy up to 70 MeV, and deuteron, ^{3}He, alpha and few kind of heavy ions are sufficiently delivered with the extraction efficiencies of 50 ~ 70 %. In the past three years, we performed few improvements for the extraction system such as applying a “floating-septum” to the electric-static deflector and updating the magnetic-channel by a new one.

2.1 Floating Septum

It has been required high energy and high intensity beam extraction from the NIRS-930 cyclotron. For examples, proton beams of 40MeV x 15 μ A for ^{38}K and 65MeV x 10 μ A for SPECT are needed in the field of R.I. production, and the deuteron beam of 25MeV x 25 μ A is minimum requirements to produce high flux neutron beam for biomedical studies, respectively. In order to preserve the pre-septum electrode by the thermal damage owing to the irregular beam hitting in such the operation, we developed a “floating septum system” for the deflector. The system is composed of a new pre-septum electrode insulated from the earth potential, a beam current read-out electronics and interlock-circuit to control the ion source. The system works under the condition that, when the electric beam power on the pre-septum exceeds more than 600 W then the arc voltage of the ion source should be turn-off in an instant.

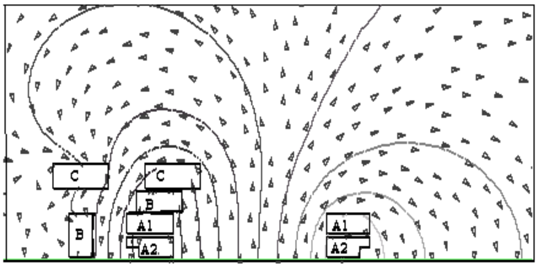

Fig. 2. Mid-plane symmetry of magnetic field distribution of the magnetic-channel.

2.2 Magnetic Channel

The magnetic-channel, which had been used almost twenty-six years since the cyclotron construction, was replaced by a new one due to troubles of the small air leak and going down the flow rate of the cooling water. The new magnetic-channel was designed and manufactured by Sumitomo Heavy Industry in Japan. On the occasion of the replacement we have checked up on the magnetic field characteristics such as field strength and field polarity for the both of the old and new one. Of course we verified the field distribution with a computer simulation by MAXWELL-2D[3] as shown in Fig.2. In resulting, those three cases were accepted as almost same stance. The temperature rise between inlet and outlet of the cooling water for an one of the longest coil (A1) as shown in Fig.2 become 65 degrees at the excitation current of 1100A in the flow-rate of 2.8 l/min.

3. APPLICATIONS

3.1 Proton therapy of the eye

The physical properties of heavy charged particles such as proton and carbon ions are uniquely suited to precise localization of radiation dose for many head and neck tumor including the orbit and eye, because of the sharp fall off of the dose at the distal end of the Bragg peak, sharp lateral edges of the beam, and ability to tailor the depth of penetration and spread of the modulated Bragg peak. The use of charged particles permits delivery of equivalent tumor dose much higher than can be delivered with standard X ray therapy, and accordingly, higher local control and survival rates are possible. The use of proton for irradiation of uveal melanoma began in 1985 at NIRS.

We developed irradiation port for the eye treatment using a vertical course of the 70MeV proton beam. Patient relax to taking treatment on a flat treatment couch, patient immobilization devises are simple and comfortable. From 1985 to 1996 eye irradiation was conducted without compensator and fine pitched bar ridge filters, which gives conformal dose distribution. We had treated 95 patients until end of March 2000. From 1985 to 1997 we had treated 65 patients without compensator and fine pitch bar ridge filters. The local control rate of the patients is 88% and enucleate rate is 31%. From 1997 to 2000 patients were treated with compensator and fine pitch bar ridge filters show that only 8% patients were enucleated for complications and 96% local control rate.

3.2 Production of Short-lived Radio-pharmaceuticals

In a recent few years, short-lived isotopes such as ^{11}C, ^{13}N, ^{15}O, ^{18}F and ^{38}K have been produced routinely by using two cyclotrons, i.e., NIRS-930 and HM18, and labeled to biologically interesting compounds. They were mainly used for the studies of brain function, cancer imaging, myocardial blood flow measurement and so on, in conjunction with PET (positron emission tomography) cameras (three for human study and two for animal study). [^{11}C]methionine and [^{18}F]FDG have been routinely produced to evaluate the effectiveness of the cancer therapy by heavy ions from HIMAC. Many ^{11}C-labeled radiopharmaceuticals, [^{11}C]MP4A, [^{11}C]FLB457, [^{11}C]WAY100635, [^{11}C]raclopride, [^{11}C](+)McN5652-X, and [^{11}C]Ro15-4513 etc. have been produced and used for the diagnosis of psychoneurosis, i.e., schizophrenia, depression, Alzheimer's disease, etc. [^{13}N]NH_3 [4] and [^{38}K]K^+ have been used for the evaluation of a myocardial and renal blood flow, and [^{15}O]H_2O for A new apparatus was installed to irradiate solid targets and to transfer the irradiated target remotely. It is coupled with a He gas and a water cooling device, a robot for remote handling of the irradiated target and a truck system to transfer the target to a hot cell for chemical processing. Metallic radionuclides (^{52m}Mn, ^{52}Fe, ^{61}Cu, ^{6}2Zn, etc.) and radiohalogens (^{76,77}Br, ^{123,124}I, etc.) are planed to be produced.

3.3 *Bio-physics study*

Since 1994, an apparatus has been fabricated for the measurement of the doubly differential cross section (DDCS) of electron emission from water vapor with fast heavy-ion (6-25 MeV/n) impact[5]. Recently, we precisely measured the DDCS (5-1000 eV and 30-150°) with the impact of 6.0 MeV/n α particles (~ 50 nA at the target). The vacuum in the chamber was of the order of 10^{-8} Torr, and the back ground level was suppressed down to 2-3 cps under beam ON and water vapor jet OFF. Binary collision peaks (several keV) and the K-LL Auger peak of oxygen (~ 500 eV) were clearly observed, as shown in Fig.3.

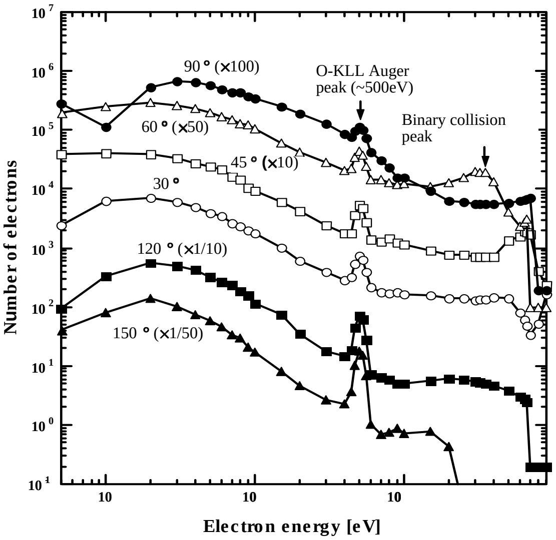

Fig.3. Electron emission from water vapor with the impact of 6 MeV/n α particles. Observed angles were 30, 45, 60, 90, 120 and 150 degrees.

3.4 *Performance of a Phoswich Neutron Detector for Space Application.*

The measurement of neutron energy spectra is a difficult problem in a large human spacecraft, because a flight neutron spectrometer needs properly to discriminate neutrons from charged particles. For this purpose, we have developed the phoswich neutron spectrometer[6], which consists of a NE213 organic liquid scintillator surrounded by a thin NE115 plastic scintillator. This detector can measure neutron spectra with discriminating neutron from charged particle using different pulse shapes of signals. The performance of the detector as a particle spectrometer was investigated in a neutron-proton mixed field produced from a 2 mm-thick ^{9}Be metal target irradiated by 70 MeV protons. Fig.4 shows the two-dimensional distribution of a particle identification. It can be clearly seen from Fig.4 that the gamma-ray events of (A), neutron events of (B) and (C), and proton events of (D) and (E) can be separated from each other. From each particle pulse-height spectra obtained by selecting each region of interest in the Fig.4, the photon, neutron, and proton energy spectra were obtained.

By using this NE115-NE213 coupled phoswich detector, the photon and neutron energy spectra can be measured in a neutron and charged-particle mixed field which is usually present in aircraft and spacecraft.

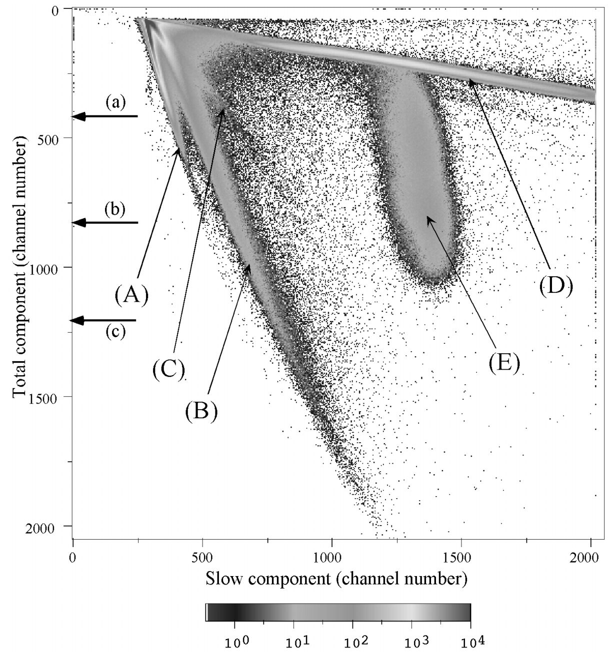

Fig.4. Two-dimensional plot of the slow component versus the total component.

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