CREATION OF $^{11}C^{+}$ ION BEAM FOR FURTHER ACCELERATION WITH HIMAC

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Abstract

At National Institute of Radiological Sciences (NIRS),、National Institutes for Quantum and Radiological Science and Technology (QST), cancer therapy with the use of a carbon beam has been successfully applied since 1994 by 'HIMAC' (Heavy Ion Medical Accelerator in Chiba). The number of treated patients has been increased to nearly 1000 per year. Meanwhile, several carbon therapy facilities for certain kinds of cancers has been also proposed and constructed in Japan. The radiation treatment with the stable ^{12}C ion beam has been well established and application of health insurance has been started from this April. Many patients, however, still suffer from refractory and/or spread-out cancers and wait for better treatments. In order to further advance the capability of carbon radiation therapy, the possibility of precise simultaneous observation of the dose distribution during real treatment with the use of positron emitting radioactive ^{11}C ion and the so-called "OPENPET" [1] has been studied by the "Projectile Fragment" scheme [2, 3]. Its intensity, however, was rather limited (~10^5 pps) and a good S/N ratio had not been attained. So as to remedy this situation, the acceleration of radioactive ions created by the "ISOL(Isotope Separator Online)" scheme has been proposed. Radioactive ^{11}C ion beam produced by irradiation of high intensity proton beam from the cyclotron has been proposed [4]. At NIRS, ^{11}C of the amount of about 10^{13} are produced in 20 minutes with the $^{11}B(p, n)^{11}C$ reaction by irradiation with 18 MeV proton beams onto a solid $NaBH_4$ target. A ^{11}C beam with an intensity of ~10^9 can be provided in each 20 minutes cycle. Recent scheme utilizes irradiation onto a solid target under the vacuum condition [5]. Recently, a beam irradiation system to a solid target at a vertical proton beam line of NIRS930 has been completed [6]. In the present paper, in connection with such recent developments, a mass analysing system to guide the selected $^{11}C^{+}$ ion beam to the HIMAC and its injector has been studied.

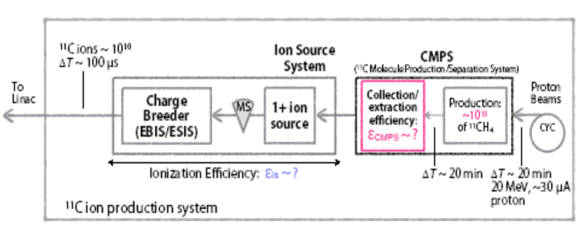

Figure 1: An "ISOL" scheme to provide ^{11}C ion beam utilizing high intensity proton beam accelerated with cyclotron [5].

Table 1: Typical Beam Intensities Required for ^{11}C Ion Acceleration

Ion Source	LINAC Output	HIMAC Extraction
$^{11}C^{4+}$ 10^{10} (100 μs)	$^{11}C^{6+}$ $5x10^9$ (100 μs)	$^{11}C^{6+}$ ~10^9 ppc$

$Extracted ion beam intensity per cycle of the HIMAC synchrotron

INTRODUCTION

Heavy ion radiation therapy has been continuously developed all over the world after the start of treatment with the use of stable ^{12}C ion beam at HIMAC in 1994. Irradiation system has also been improved from "Wobbling System" to "Scanning System", which improved the efficiency of the ion beam utilization. For the purpose of extending the applicable patients treatable by such a hadron therapy providing good quality of life, further quantitative research on radiation effects to human body has been strongly required. Clear ascertainment of the radiation area in the patient's body will enable critical treatment in such a case as a tumour exists close to an important organ. So as to improve the brightness of the OPENPET imaging with the use of positron emitting ^{11}C ion beam, development of "ISOL" scheme providing much higher intensity (~10^9 ions/cycle#) ^{11}C beam, has been pursuit by irradiation of a solid target with high intensity proton beam in vacuum [5]. In table 1, typical beam intensities required for ^{11}C ion acceleration at HIMAC with such a scheme are shown. So as to attain enough S/N ratio with the OPENPET, intensities of the order of 10^9 ^{11}C ions is needed for each cycle of HIMAC synchrotron operation, which is to be provided by the scheme shown in Fig.1.

RADIOACTIVE ISOTOPE PRODUCTION

Radionuclide Production with Cyclotrons at NIRS

Utilizing two cyclotrons existing at the Cyclotron Room, various radionuclides, listed up in table 2 and table 3, have been produced and provided for use from the AVF Cyclotron, NIRS930 and the small cyclotron, HM18, respectively. In addition to the targeted radionuclide therapy proposed in a future project by NIRS, a possible

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cycle means one cycle of the HIMAC synchrotron

Table 2: Ion Beams from the NIRS930 Cyclotron and their Created Radionuclides

Beam Particle	Radionuclide
Proton	^{89}Zr
	^{11}C
	^{62}Zn/^{62}Cu
	^{68}Ge
	^{67}Cu
H_2^+	^{64}Cu
	^{124}I
Deuteron	^{177}Lu
Helium	^{67}Cu
	^{43}Sc
	^{47}Sc
	^{74}As
	^{155}Tb
	^{186}Re
	^{211}At
	^{28}Mg

Table 3: Ion Beams from HM-18 Cyclotron and their Created Radionuclides

Beam Particle	Radionuclide
Proton	^{11}C
	^{13}N
	^{18}F
Deuteron	^{15}O

acceleration of radionuclides to higher energies with use of HIMAC synchrotron has been investigated [5,7,8]. Main goal of such an approach is at the moment to provide $^{11}C^{6+}$ beam with enough intensity (~10^9 ppc#) to realize clear imaging with "OPENPET" improving S/N ratio. If such "ISOL" (Isotope Separator Online) system works well, further possibilities to utilize other unstable ions such as ^{10}C or ^{9}C and so on might be also pursuit in order to investigate the possible higher biological effectiveness [9].

Effective Collection of Produced Radioactive Ions

For our purpose to utilize produced radioactive ion beam for medical treatment and/or imaging, suppression of contamination is as well important as the high production rate, because such contamination will often cause toxicity. In our scheme, irradiation with the high intensity proton beam is applied in a vacuum system to avoid large contamination from the air and a solid target is utilized to collect efficiently produced radioactive material included in gas molecules. Therefore a small condensation of the molecule including the radioactive atom into the solid state target is required. Here we assume a solid target of $NaBH_4$ to provide $^{11}CH_4$ gas guided by the gas chromatography [10]. Recent investigation has pointed out the capability of other target material utilization to attain higher efficiency [11].

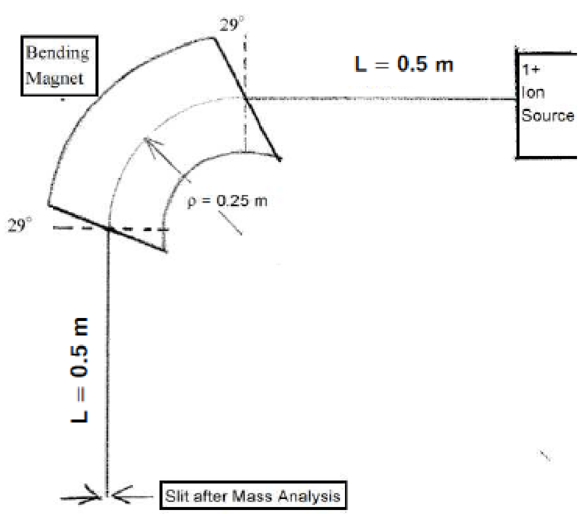

Figure 2: Mass analysis system with the use of double focusing magnet.

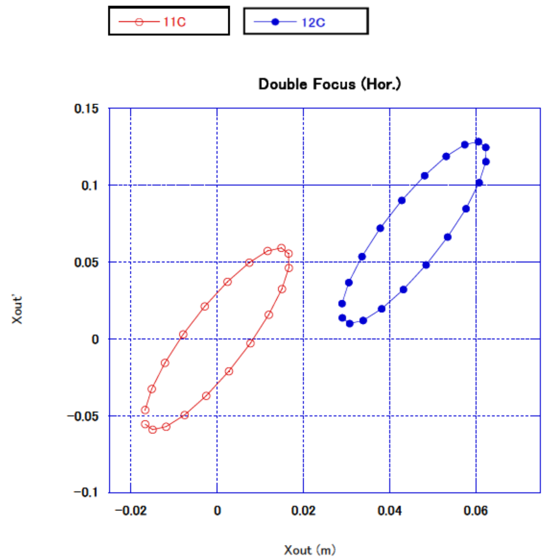

Figure 3: Distribution of the $^{11}C^{+}$ and $^{12}C^{+}$ ions .at the slit after the double focusing magnet for mass analysis.

MASS ANALYSIS

The CMPS (^{11}C molecule production and separation system) is required to be followed by a singly charged ion source and a charge breeder as shown in Fig 1. $^{11}CH_4$ gas is required to be ionized to produce single charged ion $^{11}C^{+}$, which has to be separated from $^{12}C^{+}$ coming from the air. For this purpose, the double focusing dipole magnet [12] shown in Fig.2 is to be utilized. In such a situation, for a 90° deflection, the distance L between the dipole magnet and the 1+ ion source or the slit after mass analysis has to fulfil the following relation [12]:

$$L = 2\rho \quad ,$$

where ρ is the curvature radius of the magnet. We can get a point to point image both in the horizontal and vertical directions if we use an edge angle of 29° for the dipole magnet with a gap size of 60 mm. In the simple optical calculations a normalized beam emittance of 0.5 πmm・mrad is assumed. We expect the following situation if the effect of the space charge force is negligible. The single charged ions of $^{11}C^{+}$ and $^{12}C^{+}$ extracted from the 1+ ion source by the high voltage of 5 kV will be separated as shown in Fig.3 at the slit after the double focusing magnet. Their vertical distributions in the phase space are calculated to be almost

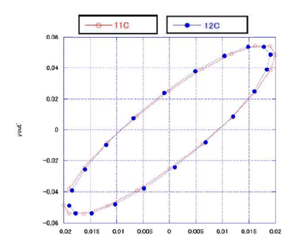

Figure 4: Distributions of ^{11}C+ and $^{12}C^{+}$ ions in the vertical phase space.

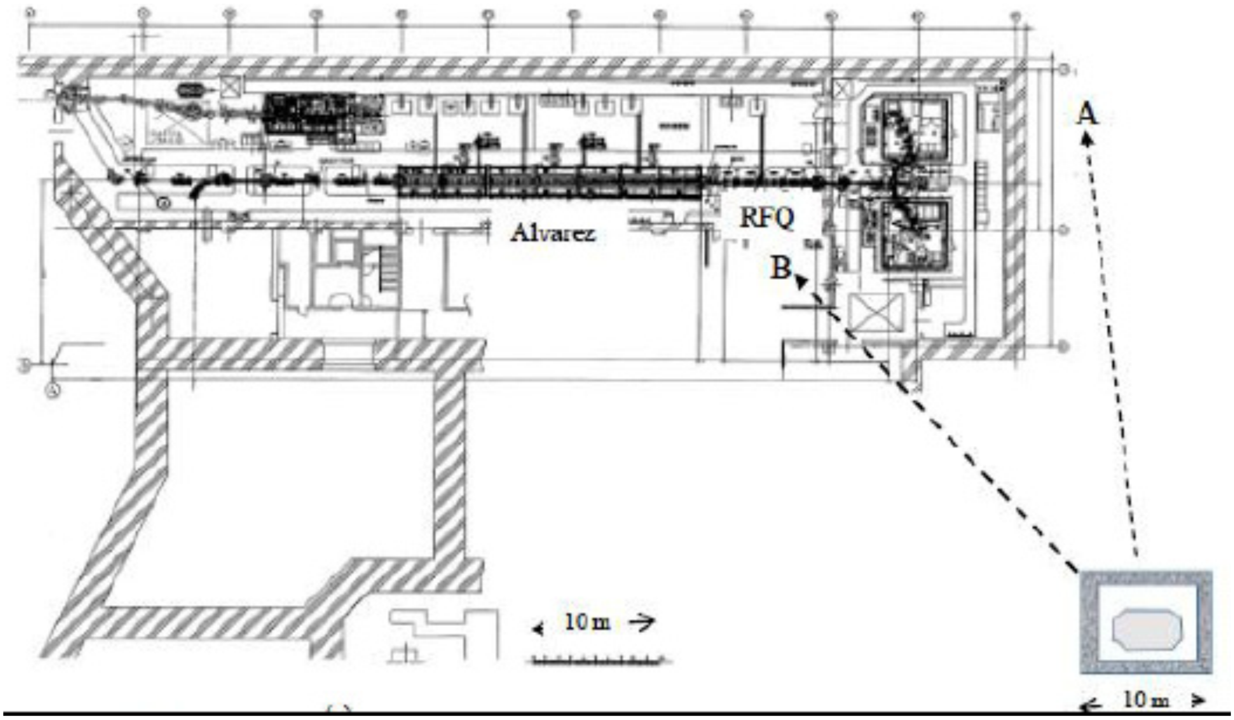

Figure 5: Layout of HIMAC and its injector and the proposed 11C radioactive ion beam production system.

the same for both ions as shown in Fig. 4. Real performance of the CMPS and following 1+ ion source and mass analyser is to be experimentally demonstrated from now on at the C3 beam line of NIRS930 [6], which is to be combined with an EBIS type charge breeder to be developed separately.

ACCELRERATION SCHEME OF ^{11}C BEAMS WITH HIMAC

As the life time of the ^{11}C is ~20 min. it is required to locate its production system just in connection with the HIMAC injector. A small cyclotron, HM-20 to produce ^{11}C ions and the following CMPS and its following scheme including the charge breeder of EBIS type, is considered to be contained into the area of the size of 10 m in length as shown in Fig.5 [8], which will be required to be discussed urgently.

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