SEPARATION AND CHARGE BREEDING SYSTEM OF RADIOACTIVE ^{11}C ION BEAM

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Abstract

Cancer therapy with the use of heavy ion beam has been developed word-wide due to its high treatment capability where the dose is concentrated close to the tumor. In order to apply such a therapy also to patients whose tumor is close to an important organ, real-time measurement of the irradiated dose distribution has been pursuit with the use of OPENPET. For the purpose of providing unstable positron emitter ^{11}C ion beam with enough intensity, target fragment scheme to be applied for re-acceleration with HIMAC synchrotron has been studied in the last few years where the irradiation is to be carried out by a high intensity proton beam from the NIRS930 cyclotron. In the present proceedings, the ion separation as well as the charge breeding system are presented.

INTRODUCTION

Heavy ion cancer therapy started for the first time at LBNL in Berkeley, USA utilizing the facility for fundamental particle physics. It has been established as a designated facility at HIMAC (Heavy Ion Medical Accelerator), which was started its operation at the National institute of Radiological Sciences (NIRS, Japan) in 1994. Until now more than 10,000 patients have been treated. At HIMAC very promising results have been obtained due to high RBE (Radio Biological Effectiveness). Recently developments where stated at NIRS to downsize the facility with the use of super conditioning technology to reduce the size and cost of the facility. Many patients, however, whose tumours locate near important organs could not receive heavy ion treatment due to such a risk as dose irradiation error cause a serious problem. At NIRS, an OPENPET has been realized [1] in order to enable the real-time observation of the dose distribution and a ^{11}C beam created by "Projectile Fragment Scheme" has been applied, however, the intensity was limited and enough S/N ratio could not

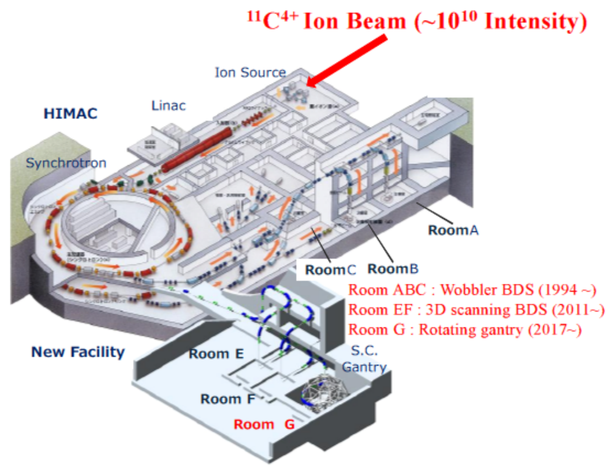

Figure 1: Layout of HIMAC together with the possible ^{11}C^{4+} ion beam injection (borrowed from [2]).

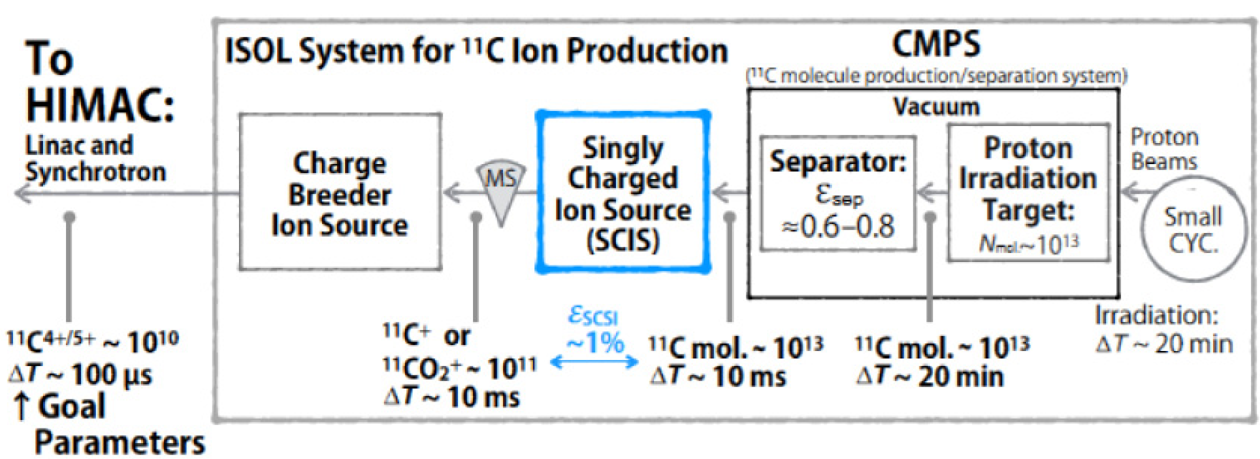

Figure 2: Sketch of the unstable ^{11}C^{4+} ion beam production for re-acceleration at HIMAC.

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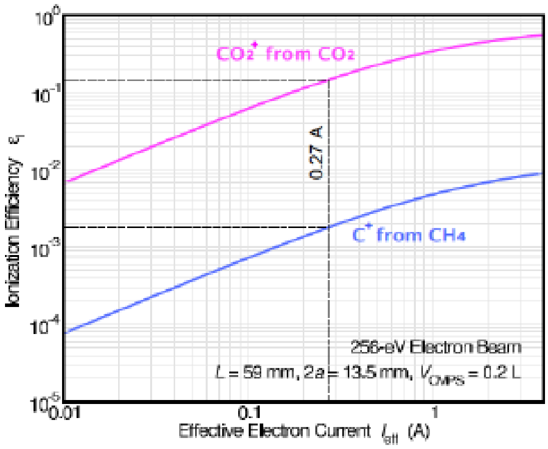

Figure 3: Ionization efficiencies for the CO_2^+ production from CO_2 and C^+ production from CH_4 molecules [8].

be realized [3,4]. A "Target Fragment Scheme" based on "Isotope Separator Online (ISOL)" system has been also investigated [5,6,7]. Based on the recent research pointing out higher ionization efficiency utilizing CO_2 molecules [8,9], we propose a really applicable scheme for re-acceleration of unstable ^{11}C ion beam created with a high intensity proton beam from a cyclotron with the use of HIMAC as illustrated in Fig. 1.

PRODUCTION PROCESS OF ^{11}C IONS

The scheme to provide unstable ^{11}C ion beam is shown in Fig. 2. "Carbon Molecule Production/Separation system" (CMPS) irradiated by a high intensity proton beam from a cyclotron provides unstable molecular ion beam with a single charge to an ion source (SCIS: "Singly Charged Ion Source"). The single charged molecular ion beam will be mass analysed and separated from bulk amount of background with stable molecular $^{12}CO_2^+$ ions and then is guided to the charge breeder to increase charge state to 4^+

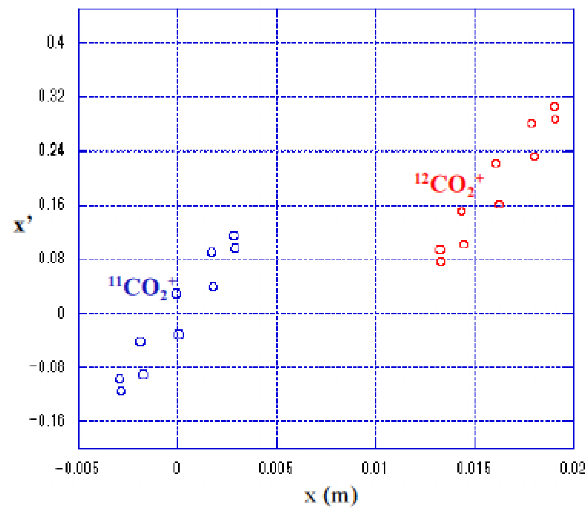

Figure 5: Molecular ion beams distributions in the horizontal phase space at the BEAM Slit in Fig. 4. It is well expected that $^{11}CO_2^+$ can separated from $^{12}CO_2^+$.

needed for the acceleration by HIMAC and its injector. For the purpose of providing unstable ^{11}C ion beam for reacceleration at HIMAC, we had assumed the usage of the dissociating process $^{11}CH_4^+$ to $^{11}C^+$ until recently [5,6], however, it was found that this process was interfering with $^{12}CH_3^+$, which could not be separated from $^{11}CH_4^+$, theretofore a $^{11}CO_2^+$ production in the target is proposed. The efficiency of the CO_2 ionization is shown in Fig. 3 [8].

MASS ANALYZER

The usage of CO_2^+ molecular ions instead of C^+ ions, however, requires improvement of the mass resolution compare to the separation of 11CH4+ from $^{12}CH_4^+$ be better than 1/44 and forced us to introduce a double bend mass analyser as shown in Fig. 4 [9]. For the improvement of the

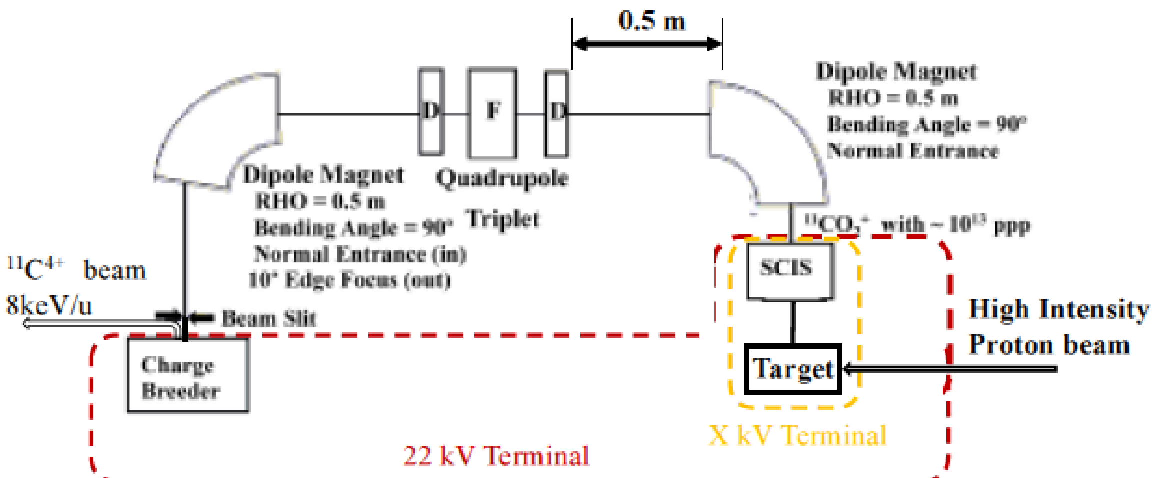

Figure 4: Total system of the $^{11}C^{4+}$ unstable ion beam production injected into the RFQ of HIMAC. $^{11}CO_2^+$ molecular ion beam is extracted from the SCIS guided to the mass analyser located on the earth potential. After separation from the large amount of residual gas background of $^{12}CO_2^+$ with this mass analyser, the unstable $^{11}CO_2^+$ molecular ion beam is injected with a kinetic energy of 40 keV into the charge breeder.

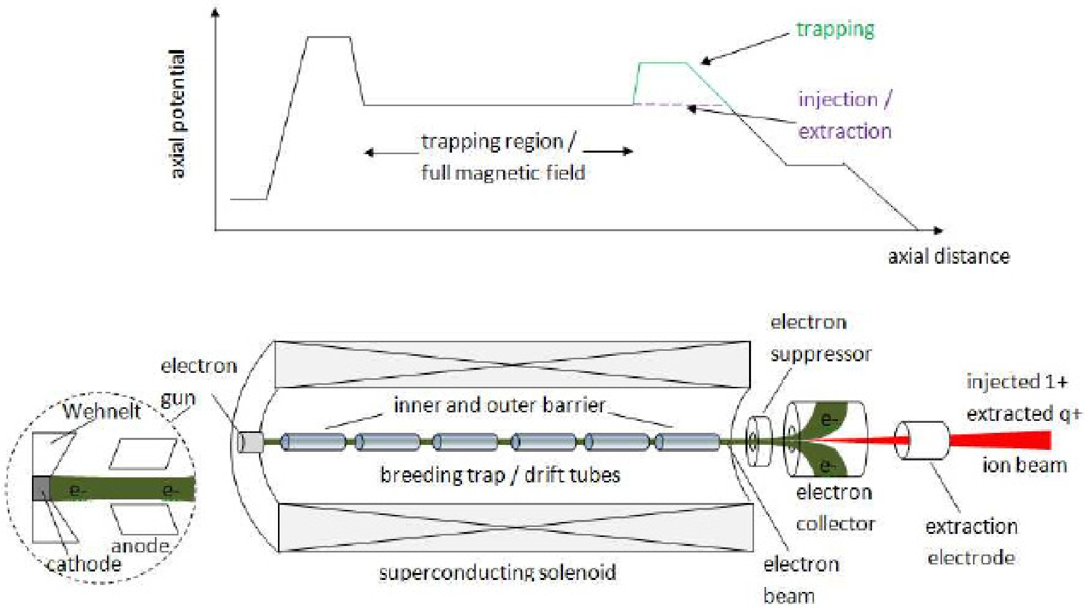

Figure 6: Typical charge breeder of EBIS type [11] to be applied for the present system.

mass analysing power, it is required to give a higher energy to the analysed ion beam. For this purpose, the target of B_2O_3 irradiated with the high intensity proton beam from a cyclotron as well the CMPS together with SCIS has to be on a high voltage platform with the potential of 22kV+X kV as shown in Fig. 4. If we assume a value of 40 kV for X then the $^{11}CO_2^+$ ions can be well separated from the $^{12}CO_2^+$ ions. $^{12}CO_2^+$ ions are anticipated to contaminate with a large amount due to the leakage from the air to the vacuum system for irradiation, as shown in Fig. 5 calculated at the beam slit position. In table 1, the parameters of the optical elements used in the mass separator to realize this separation, are given.

Table 1 Main Parameters of the Optical Elements Used in the Mass Separator (Fig. 4)

Dipole Magnet	Radius of Curvature:	0.50 m
	Bending Angle:	90°
	Edge Angle: (Exit of the 2nd dipole:	0° 10°)
Quadrupole	Length:	0.2 m (QF), 0.1 m (QD)
	Strength(n/ρ):	31.8 m^{-2}(QF) 53.0 m^{-2}(QD)

CHARGE BREEDER

For the charge breeder, there are two possibilities: The usage of an ECR or an EBIS/EBIT [10] (called as EBIB by Dr. Wenander [11], the first, however, is mainly oriented for continuous beams and is not suitable for the present case, because we want to inject the $^{11}C^{4+}$ ion beam into the HIMAC synchrotron, which requires a pulsed beam with the duration around ten times of the revolution time of the injection beam (~100 μs). Therefore we adopted an EBIS type charge breeder as shown in Fig. 6 [11], a detailed design needs some time. According to experience of the REXEBIS [11, 12], breeding efficiency is about 10 % which we use in our considerations [13].

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