At-211 製造用ビームスキャンニングシステムの開発

DEVELOPMENT OF A BEAM SCANNING SYSTEM FOR AT-211 PRODUCTION

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Abstract

Targeted alpha therapy (TAT) has become a kind of extremely efficient therapeutic method of advanced cancer. In TAT, radiopharmaceutical containing radioactive isotope At-211 is injected intravenously and delivered to a tumor, transported to the inside of cancer cells then release alpha ray to kill them accurately. For mass-production of At-211 in RCNP, a beam scanning system is required to moderate partial heat surge. Therefore, we made a calculation of beam transport and also evaluated particle distribution on the target with a wobbling scanning system, using 30MeV 4He2+ ion beam.

INTRODUCTION

Targeted alpha therapy (TAT), which is capable of killing cancer cell only, has become a kind of extremely efficient therapeutic method of advanced cancer. As illustrated in Fig. 1, in this therapy, radiopharmaceutical containing radioactive Isotope At-211 is injected intravenously and delivered to a tumor, transported to the inside of cancer cells then release alpha ray to kill them accurately.

Osaka University is planning to build an 'one stop' of TAT, from At-211 production to clinical application. In practice, concerning the decay in the time from production to dosing, it is required to mass-produce At-211 of more than 1GBq. However, in the At-211 production via Bi-209(α,2n)At-211 reaction, once the particle energy exceeds 29MeV, Bi-209(α,3n)At-210 reaction occur will occurs and creates a long half-life and toxic Po-210 by the decay of At-210. Therefore, in order to get maximum physical yield of At-211 and avoid the creation of toxic RI, it is required to keep the particle energy right below 29MeV. For the purpose of mass-production of At-211, a large beam current is required and meanwhile creates huge heating power on the target. To prevent melting down of Bi target whose melting point is about 271.5degree centigrade, efficient cooling systems is certainly required. Besides, for the heat moderation, a beam scanning system is also necessary for the production.

Therefore, we are developing a scanning system for At-211 mass-production Via Bi-209(α,2n)At-211 reaction.

AT-211 PRODUCTION IN RCNP

For At-211 production, F course in RCNP is now under upgrade, and the draft of equipment layout drawing is illustrated in Fig 2-a. Elliptic Bi target is set on an aluminum holder as Fig 2-b, and irradiated in a target chamber with 30MeV $^{2+}$He, accelerated by the AVF cyclotron in RCNP which is under upgrade. To minimum the areal power density on the target, the Bi target is set at an angle of 15 degrees to the beam. A water cooling system is installed at the back of target holder, and a gas cooling system blowing He gas at the surface of target is also ready to be introduced if necessary. Besides, for heat moderation, a wobbling beam scanning system, which is planned to scan on the target like Fig 2-c, is under development.

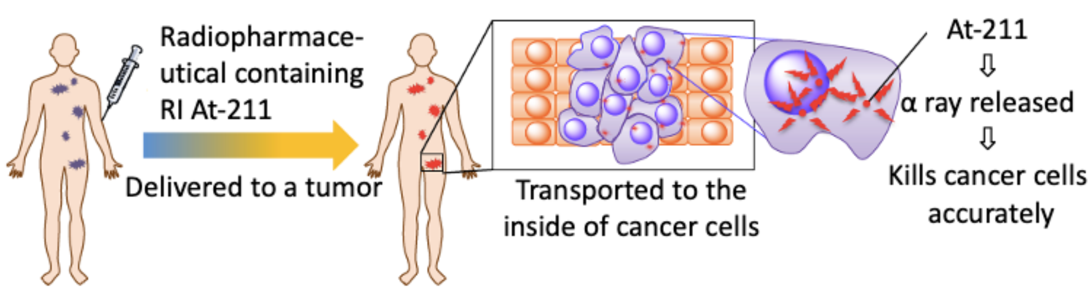

Figure 1: The process of Targeted alpha therapy (TAT).

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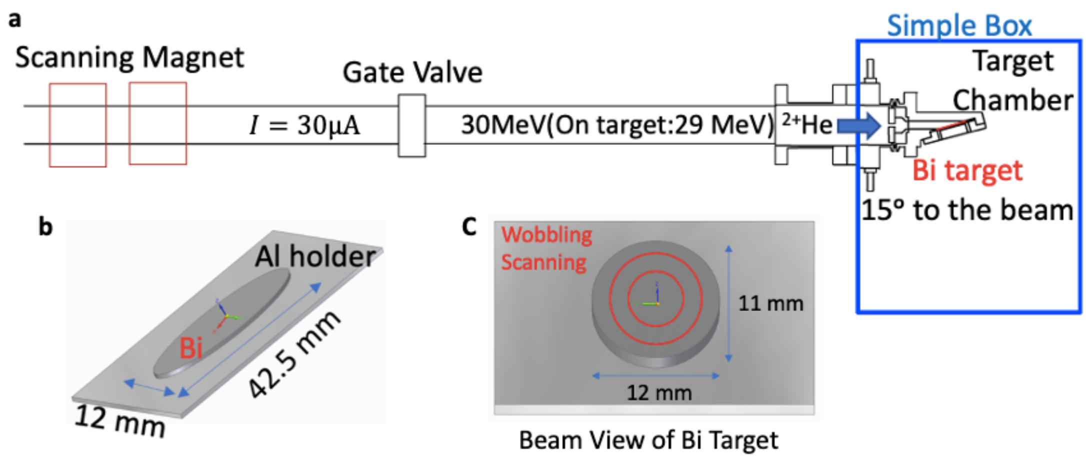

Figure 2: Production of At-211 in RCNP; **a**: draft of equipment layout in F course **b**: target size and setup **c**: scanning schematic on the target.

BEAM TRANSPORT

The results of beam oscillation and dispersion calculation is illustrated in Fig 3.

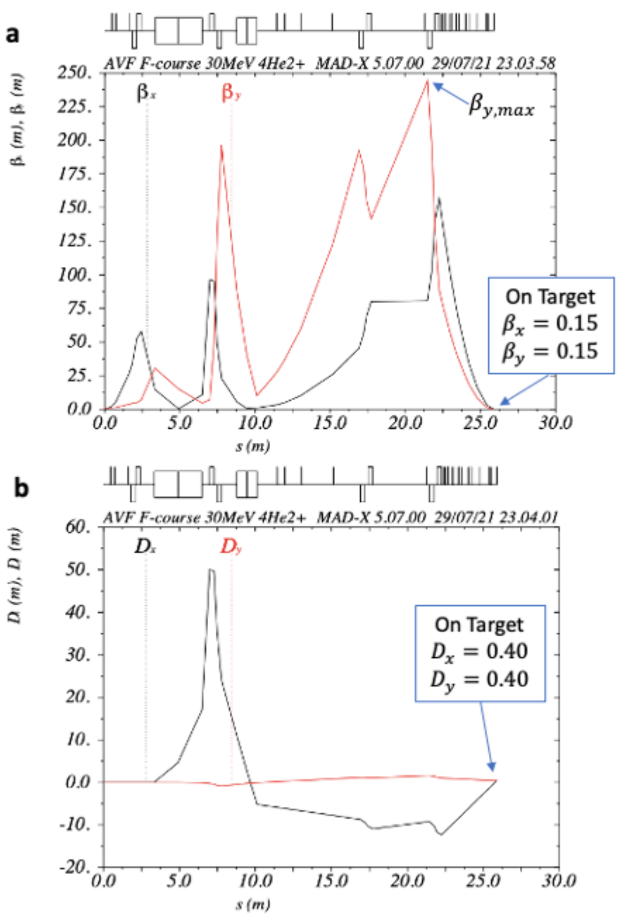

Figure 3: **a**: Beam oscillation through the beamline **b**: Beam dispersion.

Initial condition of the calculation is set as the beam spot radius is 2mm in the horizontal plane and 6mm in the vertical one. The beam emittance is ε =10π mm*mrad in both planes [1] and momentum dispersion is $\frac{\Delta p}{p_0} = 2 \times 10^3$. With the matching module of mad-x software, the beam is expected to be locked at $\beta = 0.15$ and $D = 0.4$ in both planes on the target, which indicates a beam spot of $\sigma = 1.5$ mm with Eq. (1) and the beam spot radius of $\phi = 3.0$ mm.

$$\sigma = \sqrt{\beta\varepsilon + \left(D\frac{\Delta p}{p_0}\right)^2} \tag{1}$$

The beam oscillation in the vertical plane β_y got extremely unstable and increased to a maximum of $\beta_{y,max} = 244$ m during the transport as the red broken line in Fig 3-a. The $\beta_{y,max}$ indicates that the beam spot will reach maximum of $\phi_y = 99$ mm at where is the entrance of a quadrupole magnet, whose Bore Value is $\phi = 106$ mm. Therefore, the beam might suffer some particle loss, but go through the quadrupole tightly.

PARTICLE DISTRIBUTION ON TARGET

The scanning system is introduced for heat moderation, however, as a cost, there might be a part of particle loss beyond the target when the beam spot gets closed to the edge of the target. Otherwise, if we try to minimum the particle loss by restricting the beam spot at the center of the target, the uniformity of the particle distribution will be so negative that the reaction only occurs at the center, wasting a significant portion of Bi target. Therefore, it is essential to decide the scanning orbit for the beam spot, considering the balance of the particle loss as well as the uniformity of particle distribution on the target.

For the purpose of that, we ran a calculation of the particle distribution on the target, using different numbers of gaussian distribution on the target with a spot of $\phi = 3.0$ mm earned in section 3. The essential constraint is set as the particle loss beyond the target should be less than 10%, then minimum the non-uniformity of particle distribution to the full extent. The non-uniformity is evaluated by Eq. (2).

$$\mathrm{Non-uniformity} = \frac{y_{max} - y_{min}}{y_{max} + y_{min}} \qquad (2)$$

where y_{max} and y_{min} is the maximum and minimum value of the particle distribution on the target respectively.

Gaussian	Pitch [mm]	Particle Loss [%]	Non-Uniformity [%]	Peak Distribution
4	2.8	9.9	30	0.36
5	2.2	9.9	32	0.45
6	1.8	9.8	34	0.55
7	1.6	9.8	34	0.64
8	1.4	9.8	35	0.74

Figure 4: The result of particle distribution on the target with different numbers of gaussian distribution.

The result of particle loss and non-uniformity of distribution with 4~8 gaussian on the target is shown in Fig 4. The result indicates that the non-uniformity does not vary significantly as we change the numbers of gaussian distribution on the target, while the particle loss is restricted up to 10%. Finally, the 4 gaussian distribution with a lowest non-uniformity is decided for the scanning system. And the schematic of the scanning orbit on the target with 4 gaussian distribution is illustrated in Fig 5.

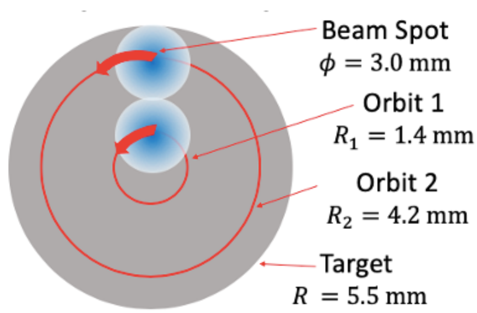

Figure 5: Wobbling scanning schematic on the beam view.

There are two circle orbits on the target, and the beam spot is moved on the orbits with a constant speed. The beam is moved for a lap on one orbit, then switched to the other orbit for another lap and repeat these steps for hours. The beam is planned to be kicked off temporarily during the switching of scanning orbit.

With this scanning system, the particle loss is restrained but the non-uniformity is a little depressing. Because the it is expected to be less than 5% for the ideal scanning system, while the best result shows that of 30%. It is thought that the best way to solve this problem is to reduce the beam spot size on the target further.

SUMMARY

Mass-production of At-211 is required for α-ray nuclear medicine treatment and we are developing a scanning system for that in RCNP. Calculation of beam transport(F course) ,so far, indicates that the minimum on target beam spot size could be $\phi = 3.0$ mm. With a wobbling scanning system, theoretically when we restrict the particle loss beyond the target within 10%, the non-uniformity of particle distribution will be up to 30%, using a beam spot of $\phi = 3.0$ mm.

REFERENCE

[1] 森信俊平「BV2b を原点とした F コースへの AVF ビーム輸送」, 2013.