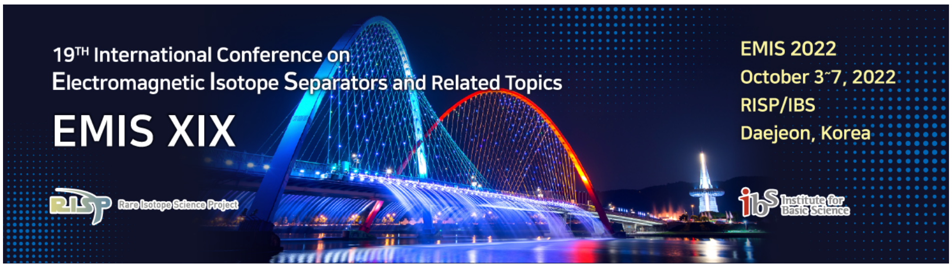

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New applications of positron-emitting nuclei in medical imaging and treatment at GSI

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In comparison to protons, carbon ion radiotherapy (CIRT) offers a promising treatment alternative due to its prominent Bragg peak, reduced lateral scattering, and high linear energy transfer (LET). Due to these characteristics, a higher conformal dose deposition to the tumor volume is possible, while sparing as much healthy tissue as possible. In 1994, the National Institute of Radiologic Sciences (NIRS) in Japan began the first CIRT, at HIMAC in Chiba, followed by Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany, in 1997, and thereafter by other facilities.

One of the major challenges of CIRT is the lack of accuracy in the image guidance systems. This is due to the inherent uncertainties in the conversion from X-ray computer tomography (CT) data to particle stopping powers, ranges, positioning of the patient, and anatomical changes. Uncertainty in the location of dose deposition requires larger safety margins for the tumor in the treatment planning, which results in irradiation of a larger volume of normal tissue. An established technique for the range verification in CIRT is positron-emission tomography (PET) imaging of the positron emitters produced by the fragmentation of the target and projectile. GSI was the first CIRT facility to establish the "online"PET as an online range verification tool in a clinical setting. However, the use of PET for range verification in heavy ion therapy with stable beams has the drawbacks: the mismatch of the activity peak to the Bragg peak of the treatment beam, and the low photon statistics compared to that of a positron emitter. A promising way forward is to use short-lived positron emitters as therapy beams. The technique was pioneered by Lawrence Berkeley National Laboratory and at the early stage of ion-beam therapy investigations at GSI, the scope of the in-beam PET imaging using radioactive ion-beam was investigated. Further developments at HIMAC, Japan, are focused on the positron-emitting isotopes of carbon and oxygen for therapy. To date, the technique has been limited to use as a low-dose probe beam for pre-treatment range verification due to the orders of magnitude lower yield of secondary radioactive ions as compared to the primary beam intensity.

With the recent intensity upgrade of accelerators, the fragment separator FRS at GSI is now capable of delivering secondary beams of short-lived positron emitters with therapy-relevant intensities. Taking advantage of this upgrade, a European initiative on biomedical applications of radioactive beams (BARB) was launched at GSI in 2021, which aims at pre-clinical validation of in-vivo beam visualization and ion-beam therapy with positron-emitting isotopes of carbon and oxygen. As a first step towards this goal, PET imaging studies of high-intensity beams of positron-emitting isotopes of oxygen and carbon at therapy-relevant energies were performed at the symmetric branch of FRS. The secondary beams, with a purity of >98% and intensities of up to 108 ions/sec, were implanted into tissue-equivalent plastic, PMMA, to produce high-quality images with a dual-plane PET scanner. The main aim of this experiment was to explore the possibility of real-time range verification using positron-emitting therapy beams and conventional PET. The results on the impact of ion-optical modes of FRS (e.g., mono-energetic, achromatic) and the beam intensity on PET image quality were investigated.

The goals within the coming years are the full characterization of the dose profiles of high-intensity radioactive ion beams in preparation for pre-clinical studies, the development of a dedicated BARB detector that combines PET and prompt gammas to achieve submillimeter resolution, and the first small animal irradiation with positron-emitting beams. Another major development within the project was the setting up of the beam transport from FRS and the medical cave (cave-M) of GSI where the abovementioned experiments are conducted. The first successful delivery of the fragment beams from FRS to biomedical experiments at cave-M opened up a new application for radioactive ion beams at GSI. An overview of the field and the results from the first year of the BARB project will be presented.

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