**Contribution aux exercices de prospective 2020-2030**

***Contribution to the 2020-2030 prospective reflection***

**Sciences Nucléaires et Vivant**

*Nuclear Science and Health*

**Description détaillée de la contribution**

*Detailed description of contribution*

**Indiquer les objectifs scientifiques (2 pages max. avec figures)**

***Please indicate science objectives (2 pages max. including figures)***

Merci de préciser le positionnement des objectifs dans l’état de l’art (échelle internationale) ainsi que les liens avec des projets existants et/ou futurs.

*Please include description of motivation within (international) state-of-the-art, as well as links to other projects (existing or foreseen).*

\*

**Merci de renvoyer ce document à** [PROSP2020-GT10-COPIL-L@IN2P3.FR](mailto:PROSP2020-GT10-COPIL-L@IN2P3.FR) **avant le   
1er novembre 2019**

**Please send this document to** [PROSP2020-GT10-COPIL-L@IN2P3.FR](mailto:PROSP2020-GT10-COPIL-L@IN2P3.FR) **before   
november 1st, 2019**

All contributions will be published on the website https://prospectives2020.in2p3.fr/ and will be analyzed in order to regroup and highlight the topics proposed for an oral presentation at the seminar thematic at the IPHC. The seminar program will be published in early December 2019. The conclusions and synthesis of the seminar (approximately 5 pages) will be reported at symposium of restitution on all the topics, which will take place in September 2020.

At the end of the restitution symposium, a final document expressing all the priorities will be drafted. Its publication is scheduled for October-November 2020. This document will then be forwarded to universities and organizations, as well as to our Ministry of guardianship.

We thank you for your involvement in this important moment for our disciplined.

The working group in charge of the "Nuclear and Living Sciences" theme:

David Brasse, Sylvain David, Fanny Farget, Sebastien Incerti, Lydia Maigne, Marc Rousseau,

Hervé Seznec.

E-mail: PROSP2020-GT10-COPIL-L@IN2P3.FR

Web: https://prospectives2020.in2p3.fr/

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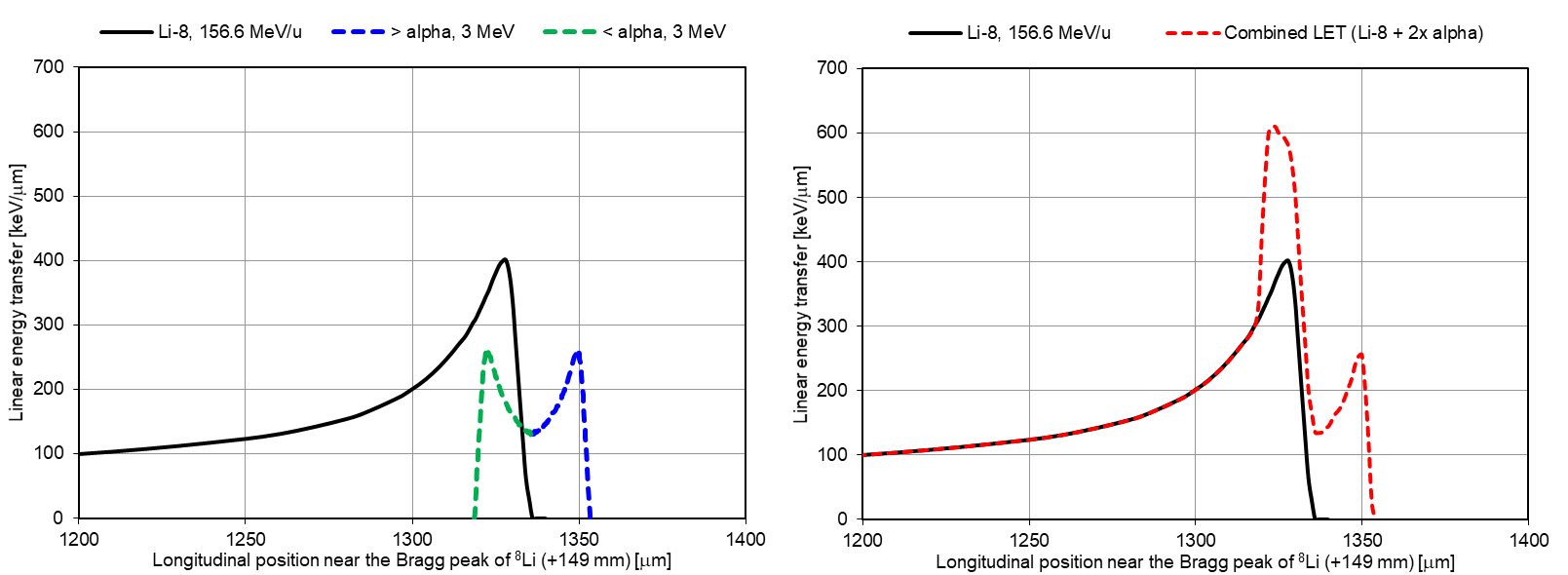
**Short-lived radioactive ion beams for radiation therapy and monitoring**

Cancer treatment by irradiation with light charged particle beams, such as protons, helium and carbon ions, possesses several important advantages compared to the conventional irradiation with X-rays [Nup14, Dur17]. The first one is related to the precision of the dose delivery including the finite range in tissue and the maximum dose deposition at the Bragg peak region, near the stopping position of the particles. This increases the radiological effect inside the tumor while preserving the healthy tissue. Another important advantage of charged particle irradiation, which increases with the mass of the ion, arises from the higher relative biological effectiveness (RBE) compared to the same dose delivered by X-rays. Additionally, heavier ions can be used for treatment of oxygen deficient tumors (radio-resistant cancers), which normally do not respond to conventional radiotherapy [Uhl14]. Due to the advantages of charged particle irradiation, there is an increasing demand for research and building of new hadron therapy centers in Europe [Dos18] and globally.

The present proposal is aiming at enhancing even further the advantages of hadron therapy by using light, short-lived radioactive ion beams (RIB) for irradiation. Light short-lived isotopes are usually beta decaying to isotopes which can be either stable or which undergo another decay before reaching stability. The recoiling daughter nuclei and the emitted charged particles share the reaction energy, which induces additional damage inside the tumor cells (see figure). The presence of the secondary energetic particles inside the tumor cells leads to the following possible advantages associated with RIB irradiation.

* The stopping of heavier secondary decay particles induces an additional energy transfer in the tumor but with a minimal damage to the healthy tissue. This leads to an **increased dose deposition in situ (DDIS)** providing an **enhanced biological effectiveness of RIB compared to both X-rays, protons and stable light ion beams**.
* Due to the origins of the decays being the stopping positions of the RIB and due to the broad energy spectrum of the secondary particles [Bar89] it is possible to achieve a uniform dose distribution in situ by combining with the spread-out Bragg peak (SOBP) of the RIB, but requiring **less beam energy steps for the same depth of the tumor, thus lowering the dose in the healthy tissue upstream the tumor**.
* Detection of either 511 keV gamma pairs from positron annihilation (in the case of low endpoint energy + decaying isotopes) or characteristic gammas from excited states of the decay products, allows estimating the stopping position of the RIB using PET and/or SPECT techniques. This allows obtaining valuable experimental data on stopping and dose distributions in both longitudinal (range straggling) and transverse (multiple scattering) planes. In addition, **PET/SPECT detection can be used for online monitoring of the primary dose deposition during radiotherapy**, which is not easy with stable light ion beams due to lower intensities of activation.

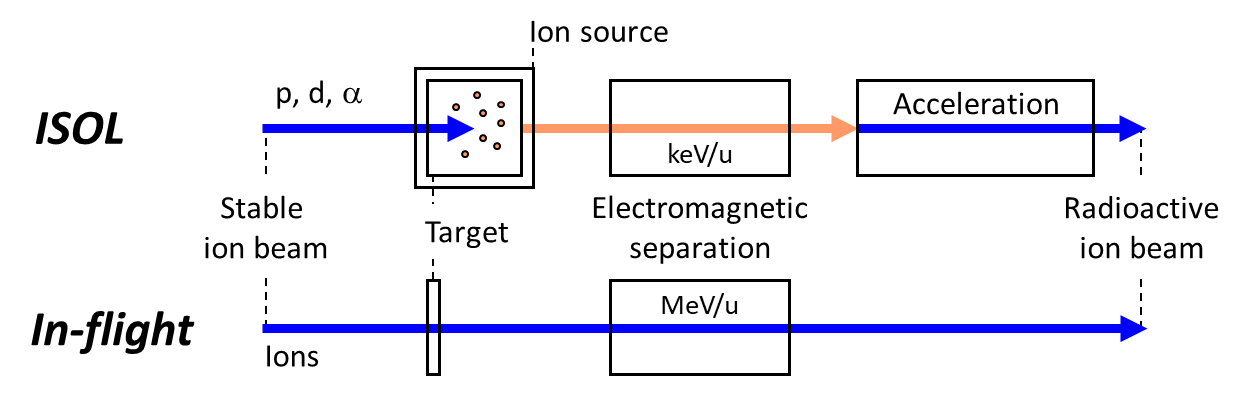
The short-lived isotopes associated with increased DDIS are selected by the localized high-energy transfer of their decay products. For dose monitoring during irradiation, both PET/CT [Cze13] and SPECT/CT [Isr19] techniques can be employed. For PET, the RIB have to be chosen to be + decaying with a low endpoint energy *E0* for higher position resolution. SPECT can be applied also for RIB associated with gamma emission during de-excitation of the decay products. Isotopes with shorter half-lives are preferable due to higher detection count rates (for monitoring) and reduced diffusion of the stopped isotopes to the surrounding tissue. The table below includes possible short-lived isotopes for RIB therapy (green) and online dose distribution monitoring (blue).

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*Comparison of the energy transfers of 8Li ion (156.6 MeV/u) and a delayed collinear emission of 2 alpha particles (3 MeV). The right plot shows the superimposed Bragg peaks of the primary RIB and the delayed alphas leading to an increase (in both height and width) of the LET near the stopping position of the RIB.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| RIB | Half-life | Decay mode | *E* [MeV/u]  *(15 cm H2O)* | Production  mode | notes |
| 8Li | 839.9 ms | -, 8Be→+ | 157 | ISOL, In-flight | Increased DDIS |
| 8B | 770 ms | +, 8Be→+ | 280 | ISOL, In-flight | Increased DDIS |
| 9Li | 178.3 ms | -, **9Be** /49.2% B.R.  -, n+(8Be→+50.8% B.R. | 147 | ISOL, In-flight | Increased DDIS |
| 9C | 126.5 ms | +, p+(8Be→+ /61.6%  +, +(5Li→p+38.4% B.R. | 327 | In-flight | Increased DDIS |
| 11C | 20.364 min | +, **11B** /99.8% B.R., *E0* = 960.5 keV  E.C. /0.2% B.R. | 289 | In-flight | Dose monitoring |
| 13N | 9.965 min | +, **12C**, *E0* = 1198.5 keV | 318 | ISOL, In-flight | Dose monitoring |
| 15O | 122.24 min | +, **15N**, *E0* = 1732.0 keV | 343 | ISOL, In-flight | Dose monitoring |
| 18F | 109.74 min | +, **18O**/96.9% B.R., *E0* = 633.9 keV  E.C. /3.1% B.R. | 354 | ISOL, In-flight | Dose monitoring |

*Light short-lived isotopes suitable for future RIB radiotherapy. Beam energy necessary for 15 cm range in water.*

Energetic RIB for irradiation can be created either by *ISOL* or by *in-flight* production methods [Blu14]. The advantages and disadvantages are well known for both methods; the former is better suited for reaching higher production rates but is highly element dependent and slower compared to *in-flight* production making it less effective for short-lived isotopes. Among the mentioned isotopes, the *ISOL* technique would be optimal for the production of 8Li and 9Li, whereas the in-flight technique may be more suited for 9C.

*Schematic description of the ISOL and In-flight RIB production schemes.*

Existing carbon treatment centers, such as HIT, MIT, CNAO, MedAustron, could be easily upgraded for RIB by adding an *ISOL* production at the ion source/injection side. *In-flight* production and separation requires acceleration of the primary beam to energies similar to the desired RIB energies. After production, desired RIB need to be separated from the primary beam and the other products. RIB may require collimation for achieving high-quality beams.

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