Optimized non-conventional radioisotopes production with industrial mid-energy cyclotron

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Objectives

While fluorine [^{18}F] is still one of the most used radionuclides in PET procedures, other metallic non-conventional radioisotopes, such as copper-64 [^{64}Cu], zirconium-89 [^{89}Zr], scandium-44 [^{44}Sc] and undeniably gallium-68 [^{68}Ga] are gaining interest as it is confirmed by growing numbers of publications.

The production of these radioisotopes usually requires more sophisticated infrastructure and their intrinsically low production yields often limit the levels of activity produced. This paper presents the solutions developed in order to increase the production rates and facilitate production processes of non-conventional radioisotopes on an industrial mid-energy cyclotron, while preserving its compactness and simplicity.

Methods

A proton only optimized cyclotron with fixed energy has been designed using the well-known internal ion source, negative ions acceleration (H-) and stripping extraction [1].

Custom energy

Standard extraction energy on the 8 exit ports is 18 MeV, which is ideal energy for high yield production of ^{18}F and ^{99m}Tc.

However, some radioisotopes require lower energy in order to limit the co-production of impurities. Usual method for lowering energy consists in using degrading foils, but the cooling capacity of such degrader will limit the acceptance current on target.

As an alternative to degrader foils, the industrial cyclotron proposes one or two exit ports that can be operated at lower fixed energy (typically between 13 MeV and 15 MeV) [2]. The control system is adapted for this setup and cyclotron operation remains simple and automated.

This feature helps to overcome the beam current limitation of the degrader foils and allows to safely increase the current on target.

High current

The cyclotron has been designed to improve performance of ion sources, beam transmission and beam extraction. This state of the art cyclotron is able to produce and sustain over extended lifetime a total beam current of up to 300 µA [3].

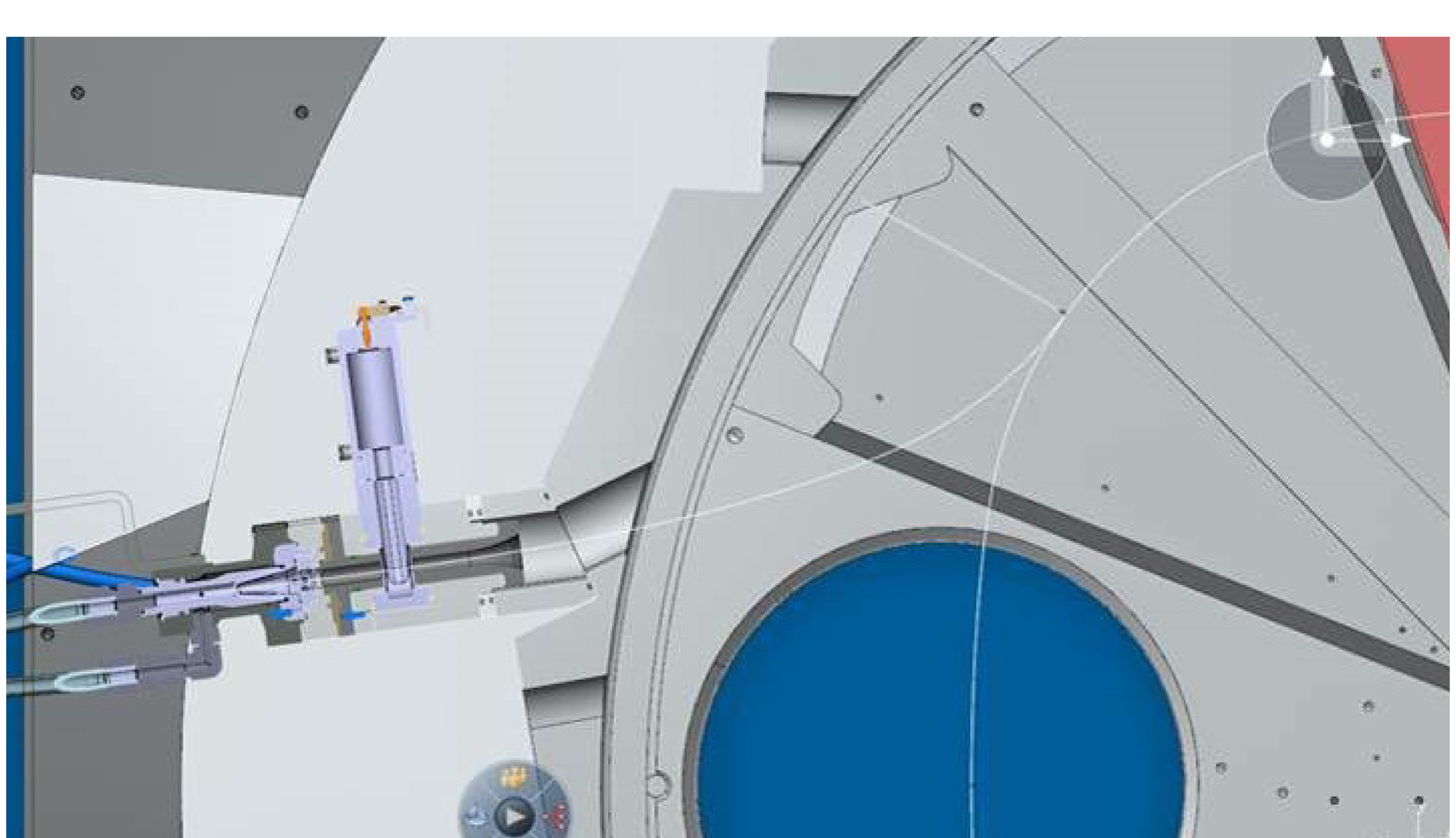
This beam can also be efficiently carried out through a beam line, which gives the possibility to fine tune the beam shape onto solid target to produce for instance ^{99m}Tc or ^{89}Zr.

High power solid target [7]

When it comes to solid target, production rates are usually limited by a low intrinsic reaction yield. Consequently, target current must be increased in order to reach higher production levels. Some solid targets have poor heat conductivity and the low power dissipation can be overcome by (i) increasing the surface area between the target and coolant; (ii) increasing the target surface in order to reduce the power density; and (iii) by using helium jets for cooling the front face of targets.

A new universal high power solid target irradiation station has been designed.

This flexible system is designed to accommodate any kind of solid target material, such as ^{64}Ni, ^{89}Y, $^{123/124}$Te... with its suitable chemistry system for purification. The system has been designed to match the performance of the optimized cyclotron, i.e. the maximum current acceptance for ^{64}Ni targets is 300 µA without degrader.



13 MeV beam optic from Cyclone® KIUBE

^{68}Ga Liquid target technology [5]

Many recent developments in the production of radiometals with liquid targets have been published [4]. Productions rates and purity levels reached for ^{68}Ga showed that this technology is a perfect viable alternative to the ^{68}Ge/^{68}Ga generators. Usual productions report production yields of 3.7 to 7.4 GBq of ^{68}Ga EOB in 1h (depending on beam current, zinc concentration, etc.) [6].

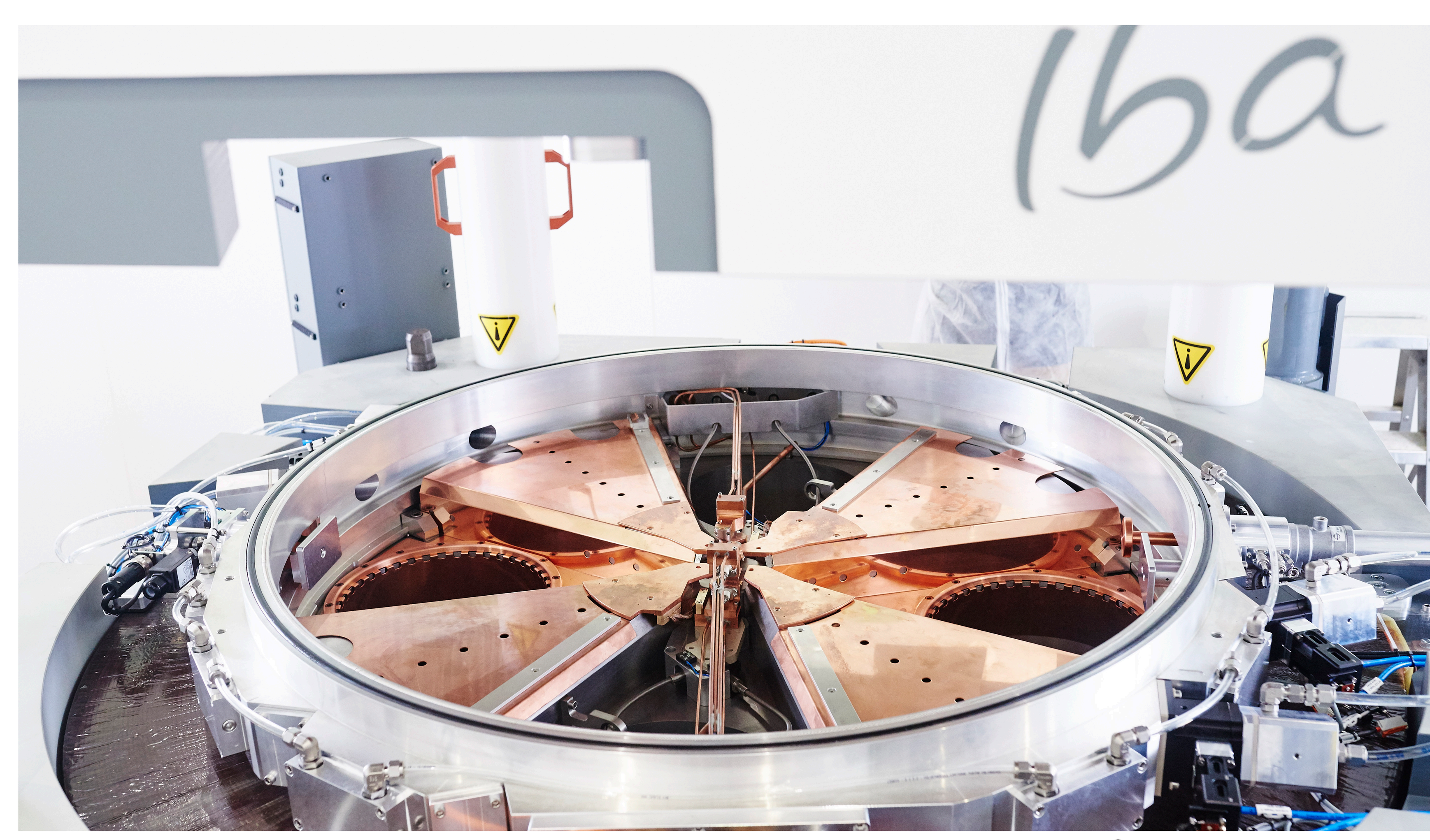
This same process has been transferred to other metallic radioisotopes. An IBA Conical target has been used to irradiate a salt solution of enriched ^{64}Ni and ^{61}Ni for the production of ^{64}Cu (T1/2= 12h) and ^{61}Cu (T1/2=3h), respectively. After 6 hours irradiation, 4.8 GBq of ^{64}Cu EOB could be obtained. ^{61}Cu has been irradiated for 45 min and 300 MBq could be produced [6].

In conclusion, the selection of a production mode for a given radioisotope will require the careful assessment of the pro's and con's of each process and the production capacity that they offer.

Results

The custom energy feature has been successfully tested in factory. Two beam exit ports (out of a total of 8) can be modified to accommodate lower proton energy on target for more effective non-conventional radioisotope production. The overall functionality of the system is not impacted (vacuum gates, current readings, etc.). The control system was also adapted to integrate the feature. Consequently, the beam energy degraders in front of certain targets can be removed and beam current on target can be significantly increased.

The high current 300 µA cyclotron was fully installed, commissioned, and accepted in 2017 [3]. The liquid target technology has now proven records and it benefits from an increasing popularity.



Cyclone® KIUBE median plane

Conclusion

Combining the cyclotron, its dedicated features, the different target technologies and the chemistry solutions, a whole range of possibilities are given to easily produce non-conventional radioisotopes. These integrated attractive solutions can be implemented in a PET radiopharmacy without compromising the large scale production of conventional PET radioisotopes.

References

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WTTC 2018, Coimbra, Portugal