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Development of a Pulsed Accelerator for Short Half Life PET Isotope Production

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INTRODUCTION

C-11, N-13, O-15 are short half-life PET isotopes that are only viable through on-site production. Traditionally, cyclotrons can generate these isotopes with large beam currents of energetic ions smashing into suitable targets. Unfortunately cyclotrons are often large and expensive to build. We propose to use a pulsed line ion accelerating (PLIA) as a cheaper and more compact alternative that operates at a high-repetition rate to produce enough beam current.

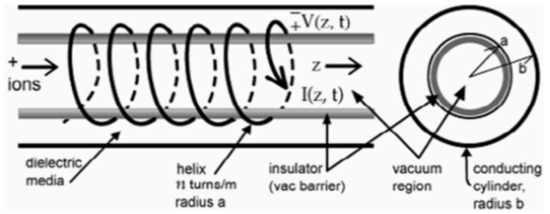
Isotope	$T_{1/2}$ (min)	Reaction	Application
^{11}C	20.4	$^{14}N(p,\alpha)^{11}C$	Brain imaging
^{13}N	9.98	$^{16}O(p,\alpha)^{13}N$	Blood flow
^{15}O	2.03	$^{14}N(d,n)^{15}O$	Brain imaging, blood flow

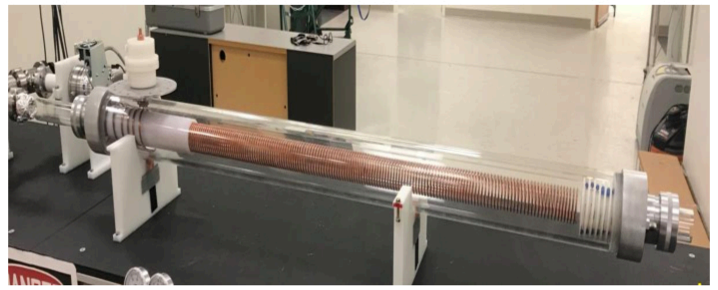
AIM

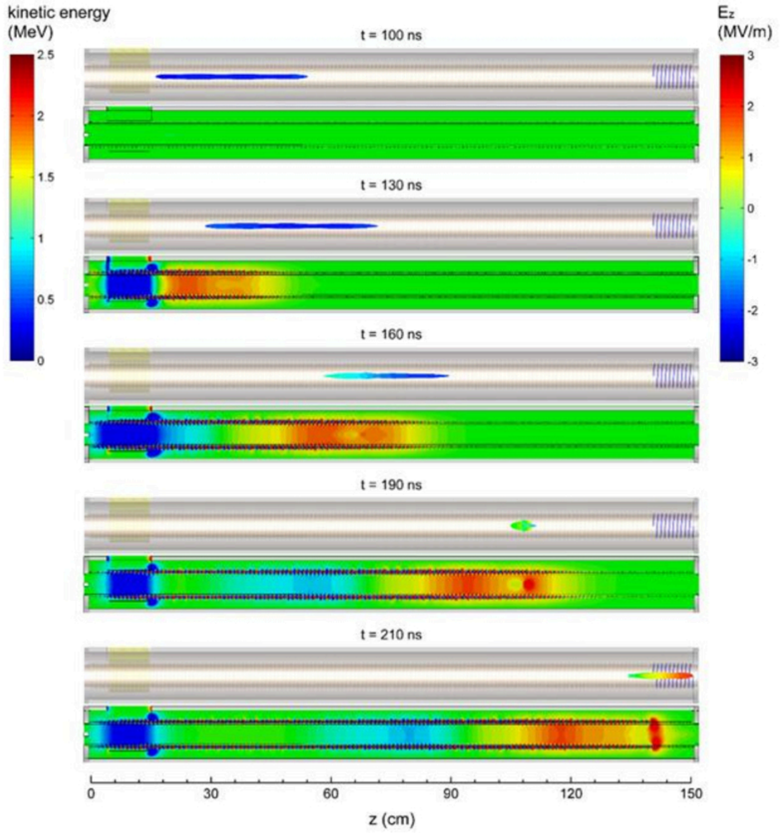
Our PLIA accelerator has a relatively small footprint compared to cyclotrons, with a much simpler design and lower cost. This makes on-site production of PET isotopes at small facilities possible, avoiding the limitations placed by the short half-lives on the possible transport distance from the production site. The high voltage gain that characterizes the spiral generator allows the use of solid state switch technology and is essential to operating at a high repetition rate, overcoming the beam current limitations that are typical of pulsed accelerator technologies.

PLIA ACCELERATOR

PLIA's principle is similar to a coaxial transmission line with a hollow center conductor where particles propagate. Applying a steep voltage ramp on the line generates a strong accelerating electric field that propagates in the hollow space







The simulation shows different timestamps for the propagation of a proton beam and the electric field.

The injected charge is equivalent to a 1A peak current. For each time point, the upper panel displays the position and kinetic energy of the proton beam, while the lower panel displays the axial component of the electric field.

This figure illustrates the slingshot acceleration strategy, whereby an incident proton bunch is injected first, followed by a faster travelling electric field wave. The wave overtakes the proton bunch, accelerating the particles in the process, until eventually the particles outrun the wave at the exit of the accelerator.

In the simulation shown, the incident 100 keV proton beam is accelerated to a maximum energy of 2.5 MeV over a distance of 1.5 m.

Briggs, R. J. (2006). "Pulse line ion accelerator concept." Physical Review Special Topics-Accelerators and Beams 9(6): 060401
Westerly, D.C., Behbahani, R.A., Kavanagh, B., Liu, A., Miften, M., Serkova, N.J. and Diot, Q. (2018), Design considerations for a pulse line ion accelerator (PLIA)-based PET isotope generator. Med. Phys., 45: 3812-3819

HIGH-VOLTAGE GENERATOR

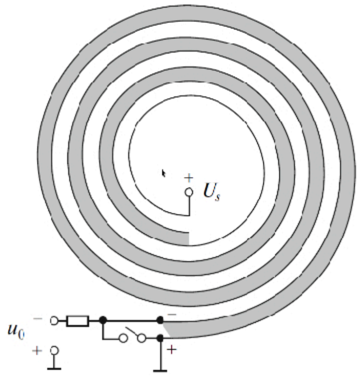
PLIA's accelerating field is dependent on the maximum amplitude of the generated short pulse.

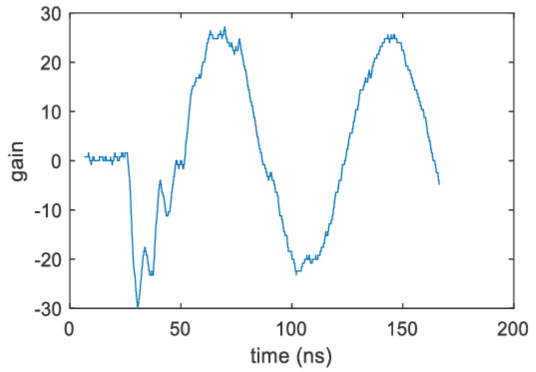
A spiral generator is a compact generator type that can produce a fast, high-voltage ramp. The generator is equivalent to a long capacitor rolled around a mandrel and terminated by a solid-state switch operating at 500Hz. The rolled design allows the output to be 10 to 50 times the charging voltage.

The pulse is triggered by closing the switch outside the spiral, which propagates an electric wave that progressively raises the voltage at the inner connector. The spiral length sets the propagation time and the oscillation period of the output.

The output signal shows a typical oscillation where the peak-to-peak slope provide an ideal voltage ramp for the PLIA. The output gain for this specific prototype was around 28 times the charging voltage.

R. A. Fitch and R. T. S. Howell, "Novel Principle of a Transient High Voltage Generator", Proc. IEE, vol. III, no. 4, April 1964





RESULTS

The compact design that associates energy storage and pulse shaping in one structure allows extremely fast switching of pulse polarity over voltage amplitudes of 500-1000 kV.

The large voltage gain signifies that the spiral generator stores and mostly operates with voltages of 10-20kV, allowing the use of high repetition rate solid-state switches and significantly reducing the chances of corona and electrical breakdown.

When coupled to PLIA, ramps as short as 40ns were observed corresponding to accelerating gradients above 3MV/m. Therefore a 3m PLIA operating at 500Hz would produce an average current of 10uA, enough to generate doses of 100s of mCi for imaging.

CONCLUSIONS

The use of a high repetition rate generator with high output voltage but significantly lower input voltage allows the safe operation of a PLIA structure with beam currents and energies suitable for short half-life PET isotope production.

CONTACT INFORMATION

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