Accelerator Systems for the Production of Medical Isotopes

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Outline

1. Introduction
2. Current system for production of medical isotopes based on cyclotron
3. Concept of novel system for production of medical isotope ^{18}F
4. Comparison of systems
5. Conclusion

Introduction

- Medical isotopes as a biomarkers found a large application for Positron Emission Tomography (PET)[1]
- The commercial cyclotrons used for the production of medical isotopes are given in the table below[2]

No	Cyclotron	Company	Country	Energy H-, MeV	Beam current H-, μA
1	Eclipse RD	SIEMENS	USA	11	2x40
2	Eclipse HP	SIEMENS	USA	11	2X60
3	Cyclone 11	IBA	Valium	10	2x60
4	Cyclone 18	IBA	Belgium	18	100/150
5	PET-Trace	GE	USA, Sweden	16.5	100
6	HM-12	SUMITOMO	Japan	12	>60
7	TR14	ACSI	Canada	18/24	>100
8	SS18	RIEE	Russia	18	100
9	TS-10	JINR	Russia	10	50

1 Directory of Cyclotrons used for Radionuclide Production in Member States 2006 Update, IAE Technical Report IAEA-DCRP/2006, Vienna, 2009

2 A.I. Papash, Yu.G. Alenitcki, “Commercial Cyclotrons. Part 1. Commercial cyclotrons in energy range 10-30 MeV for isotope production”. Physics of Elementary Particles and Atomic Nuclei, JINR, V.39, pp. 1150-1214, 2008

Siemens Cyclotron and Chemistry Solutions

Manufacturing PET cyclotrons since 1995

- Siemens Eclipse cyclotrons use to produce the medical isotope ^{18}F (primary), ^{11}C, ^{15}O

<u>The main parameters of Eclipse cyclotrons are:</u>

1. Kinetic energy of protons is 11 MeV
2. Beam current is 120μA (dual 60μA)

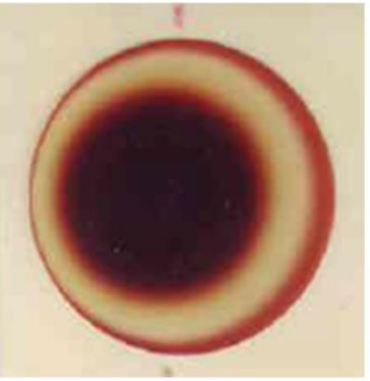
Siemens Eclipse Cyclotron

Proton beam current (dual beams mode)

Autograph of proton beam

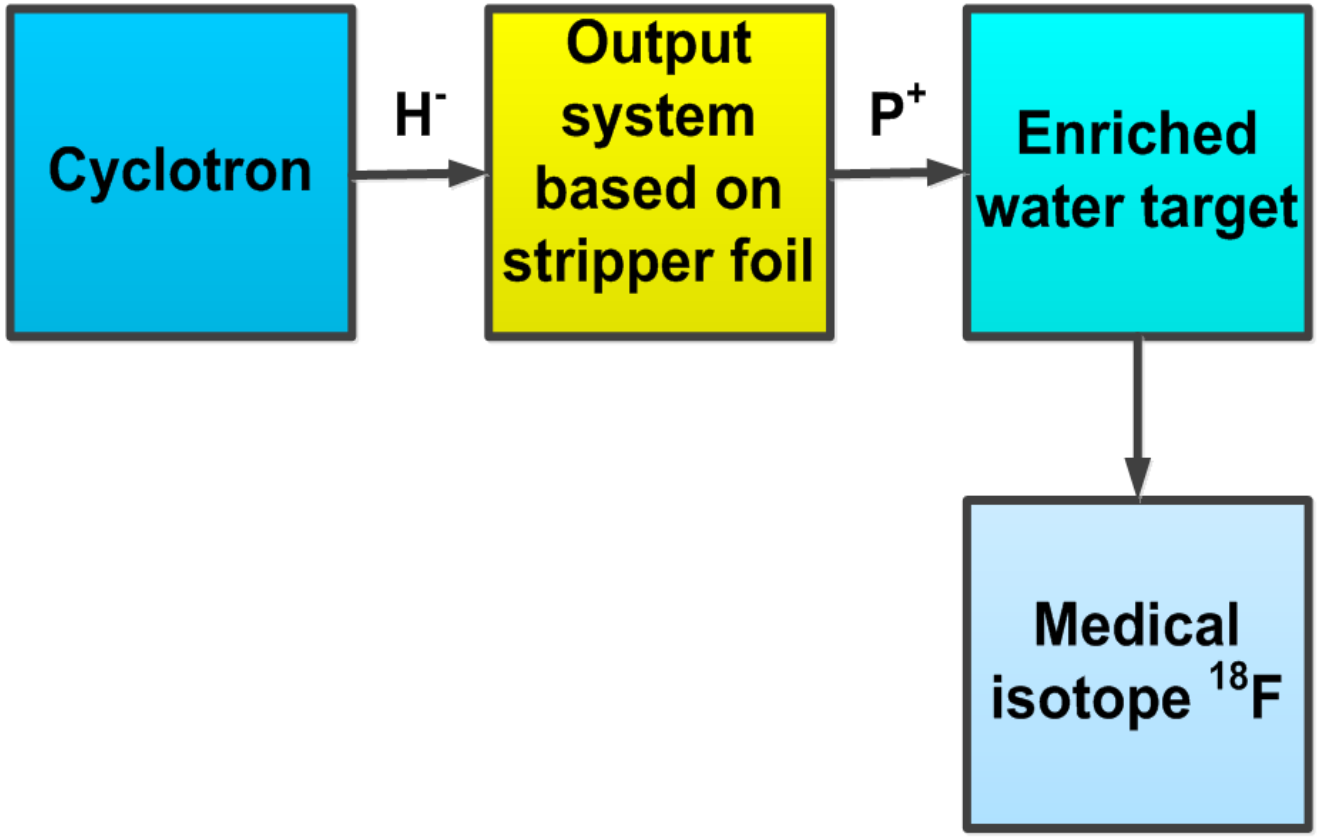
Output from cyclotron

Beam on input to target

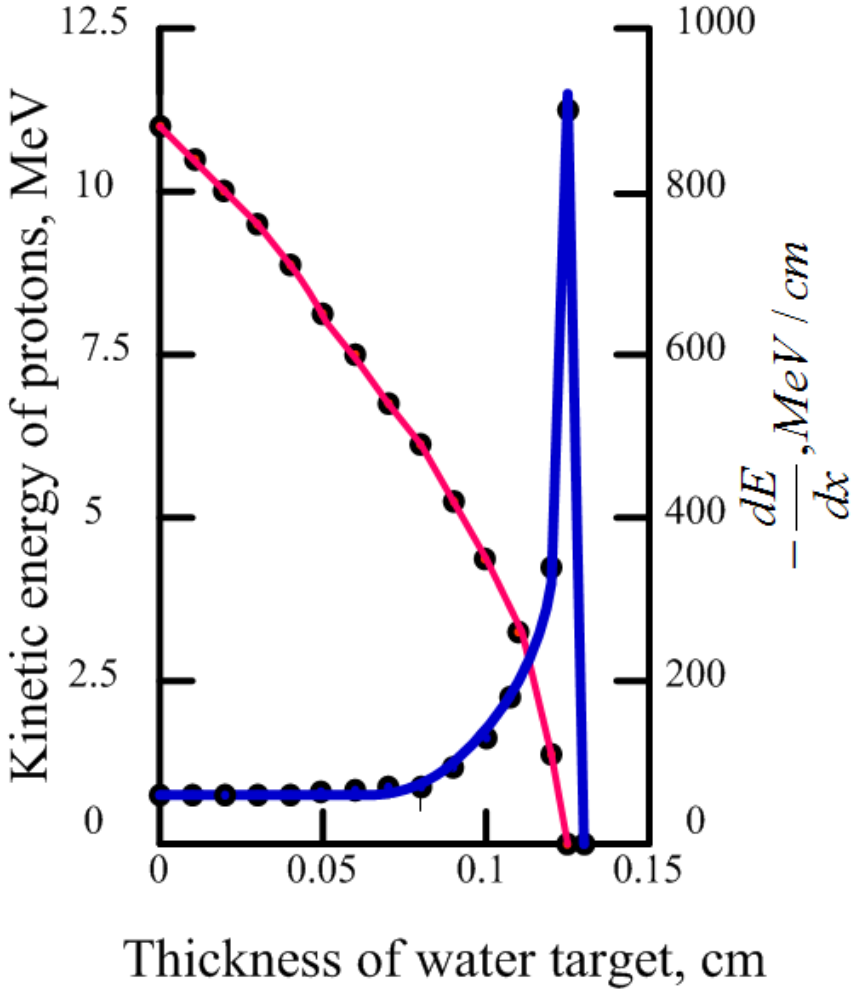


Current Method for Production of ^{18}F

- Irradiation of enriched water (^{18}O) target by proton beam for nuclear reactions with protons

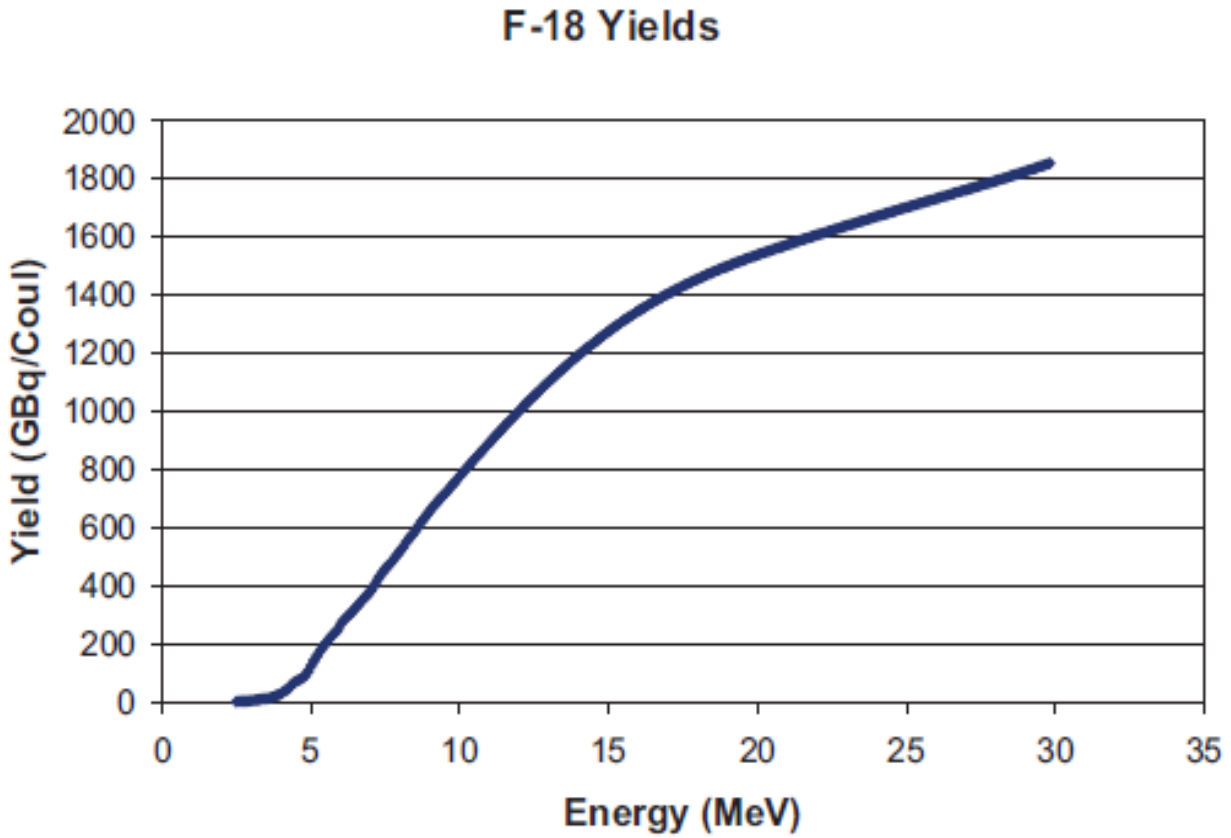


Irradiation of Water Target by Proton Beam



Yield of ^{18}F for Irradiation on Enriched Water by Proton Beam

- Two main parameters of proton beam (kinetic energy and electrical charge) determine the yield for nuclear reactions for the production of ^{18}F [3]

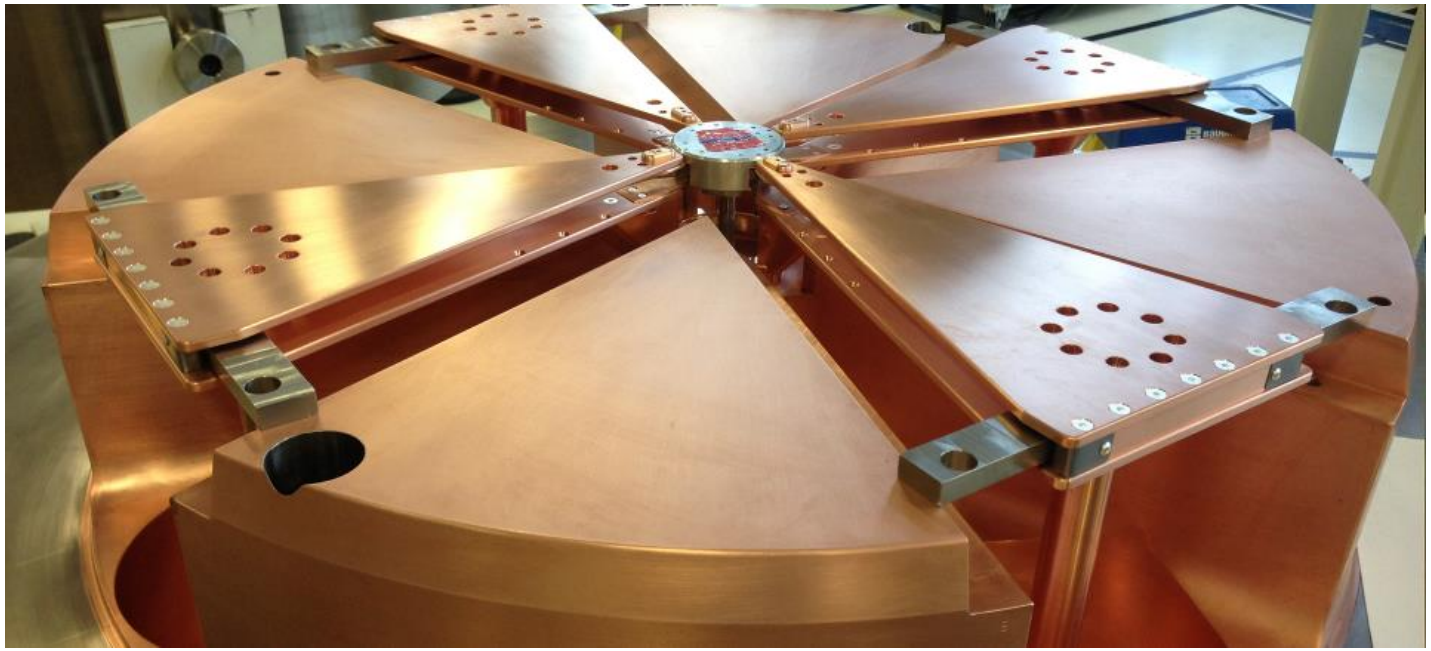


3 Report of IAEA, Pub. 1515, 2012, "Cyclotron Produced Radionuclides: Guidance on Facility Design and Production of O[18F]FLUORODEOXYGLUCOSE (FDG)"

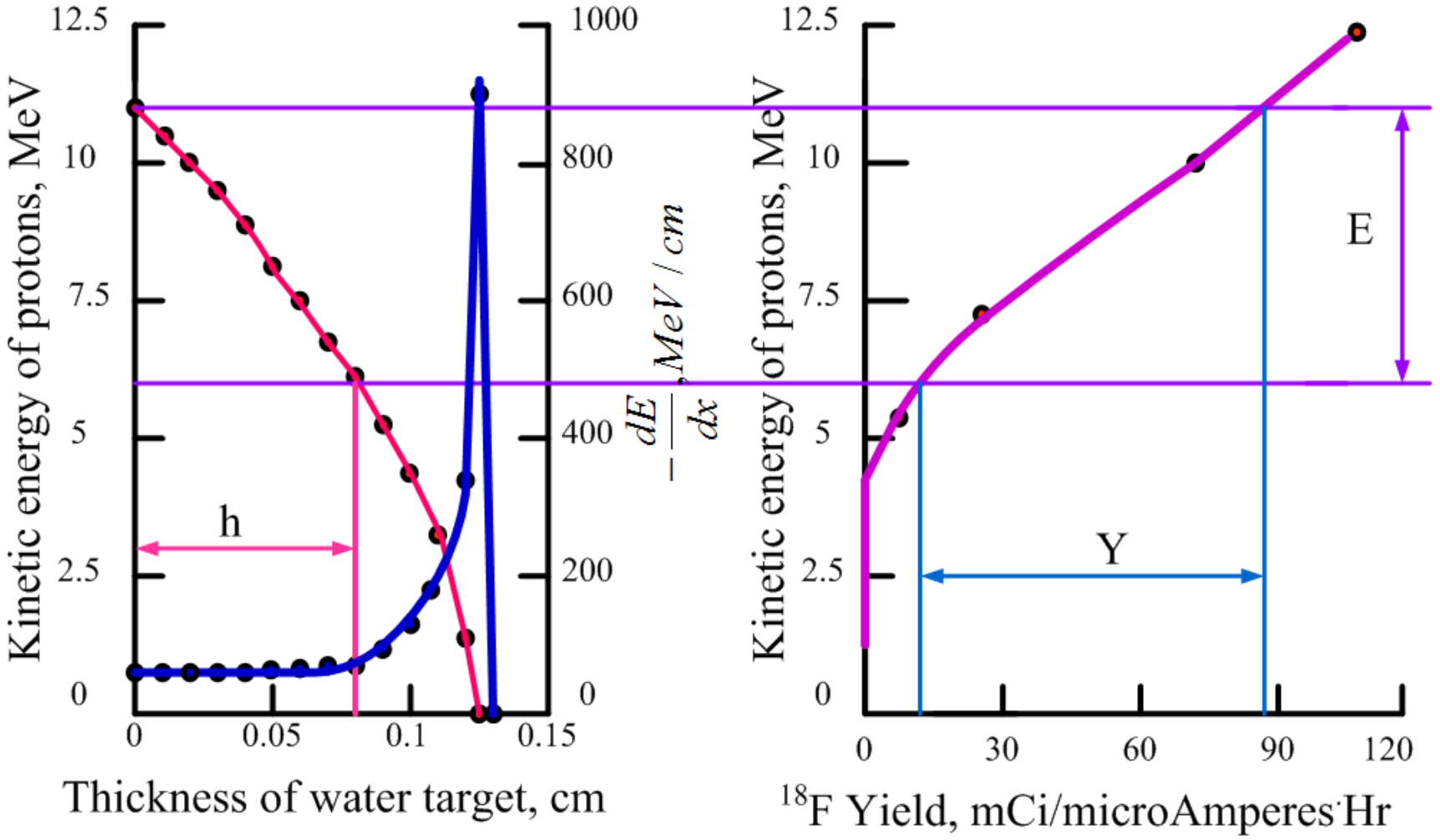
Motivation for Search of New Approaches

- Need more output – increased ^{18}F activity

- 11 MeV Eclipse has limitations:
  - Cannot increase kinetic energy - limited by size
  - Configuration of the target system



Physics of New Concept



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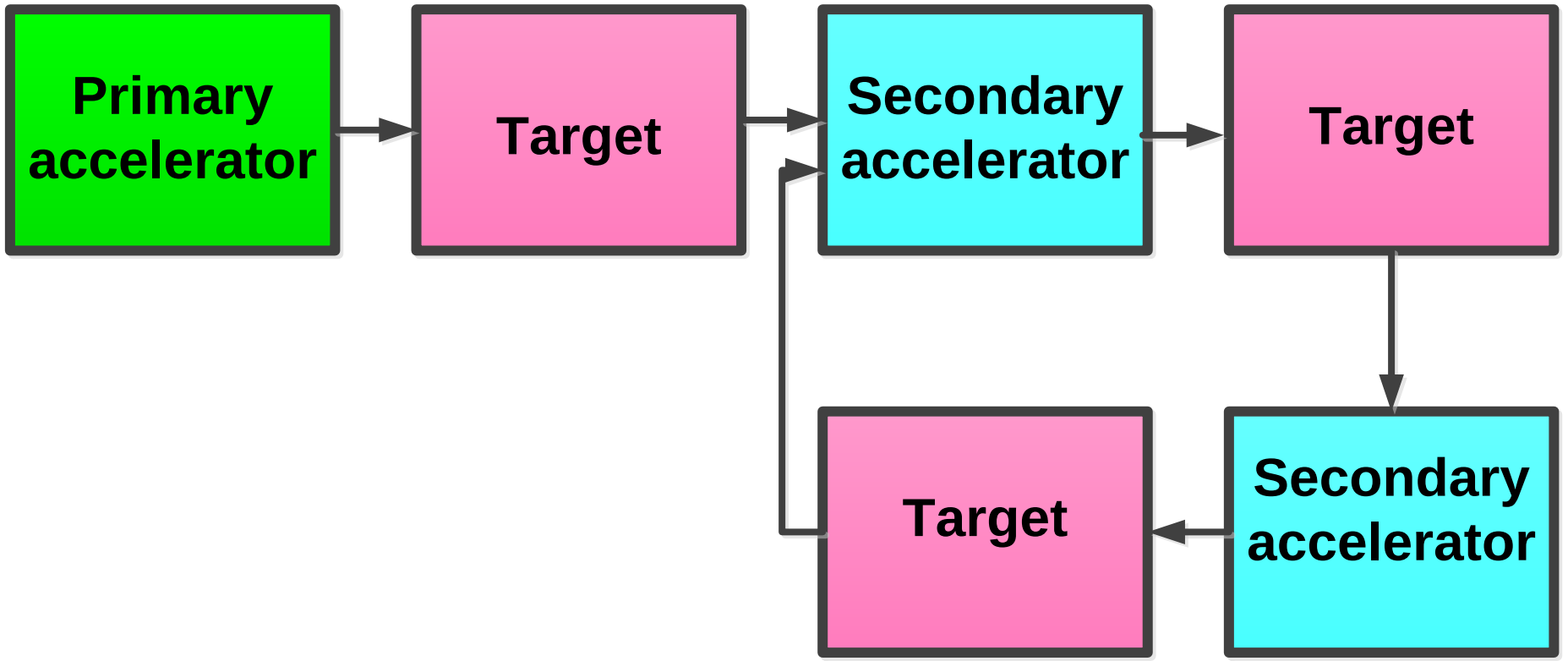
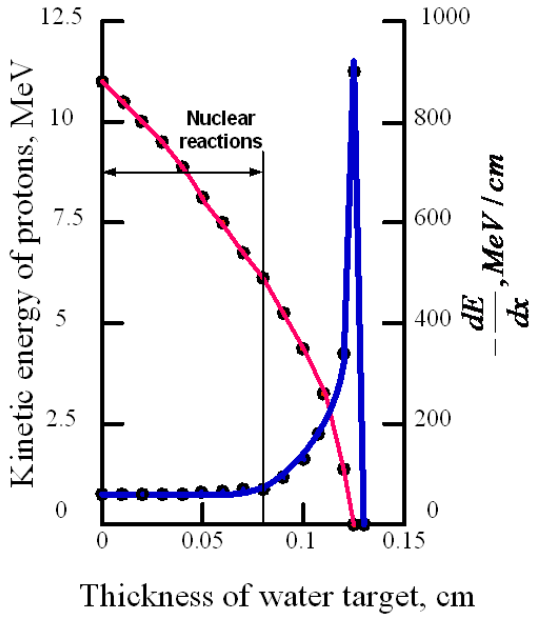
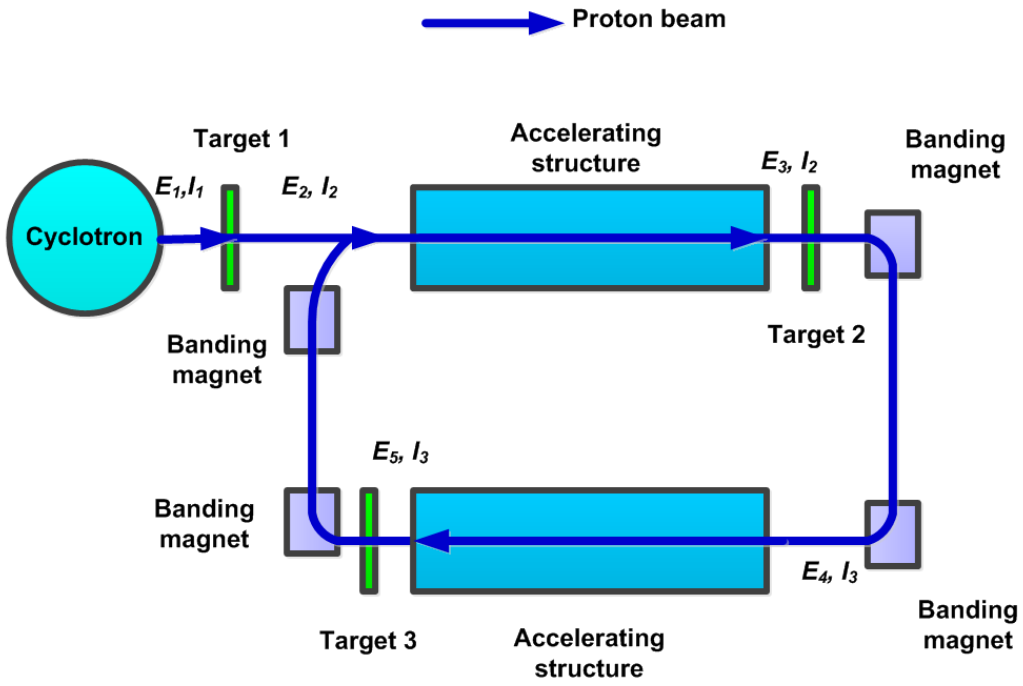
Technical Solution

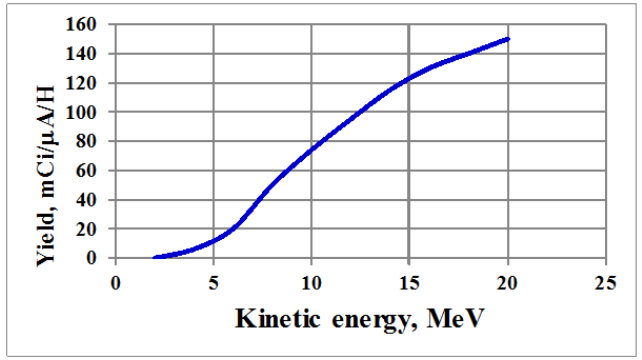
- New concept based on using the partial thickness of the target and post-acceleration of protons for multiple nuclear reactions:



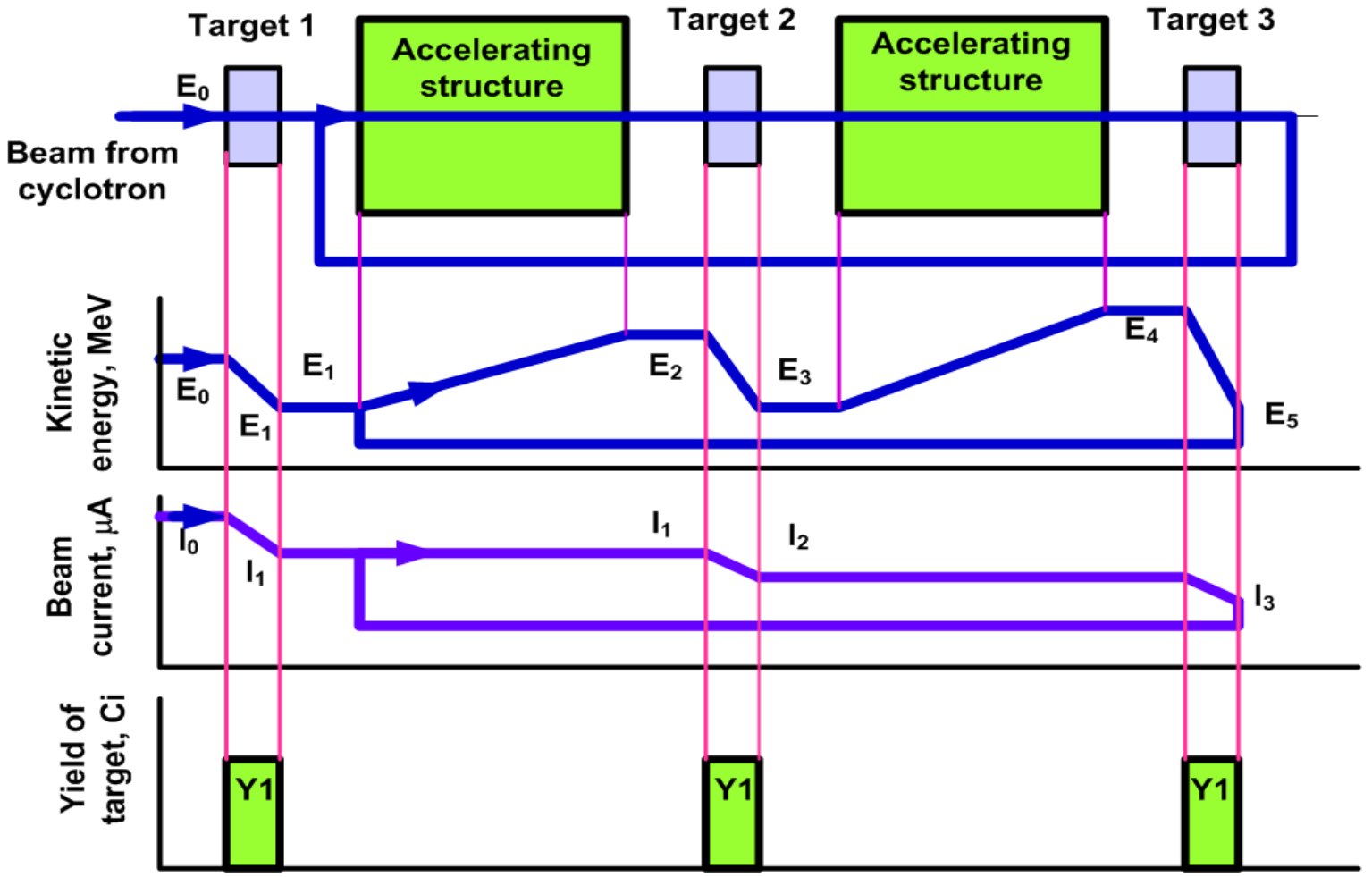
Accelerator System





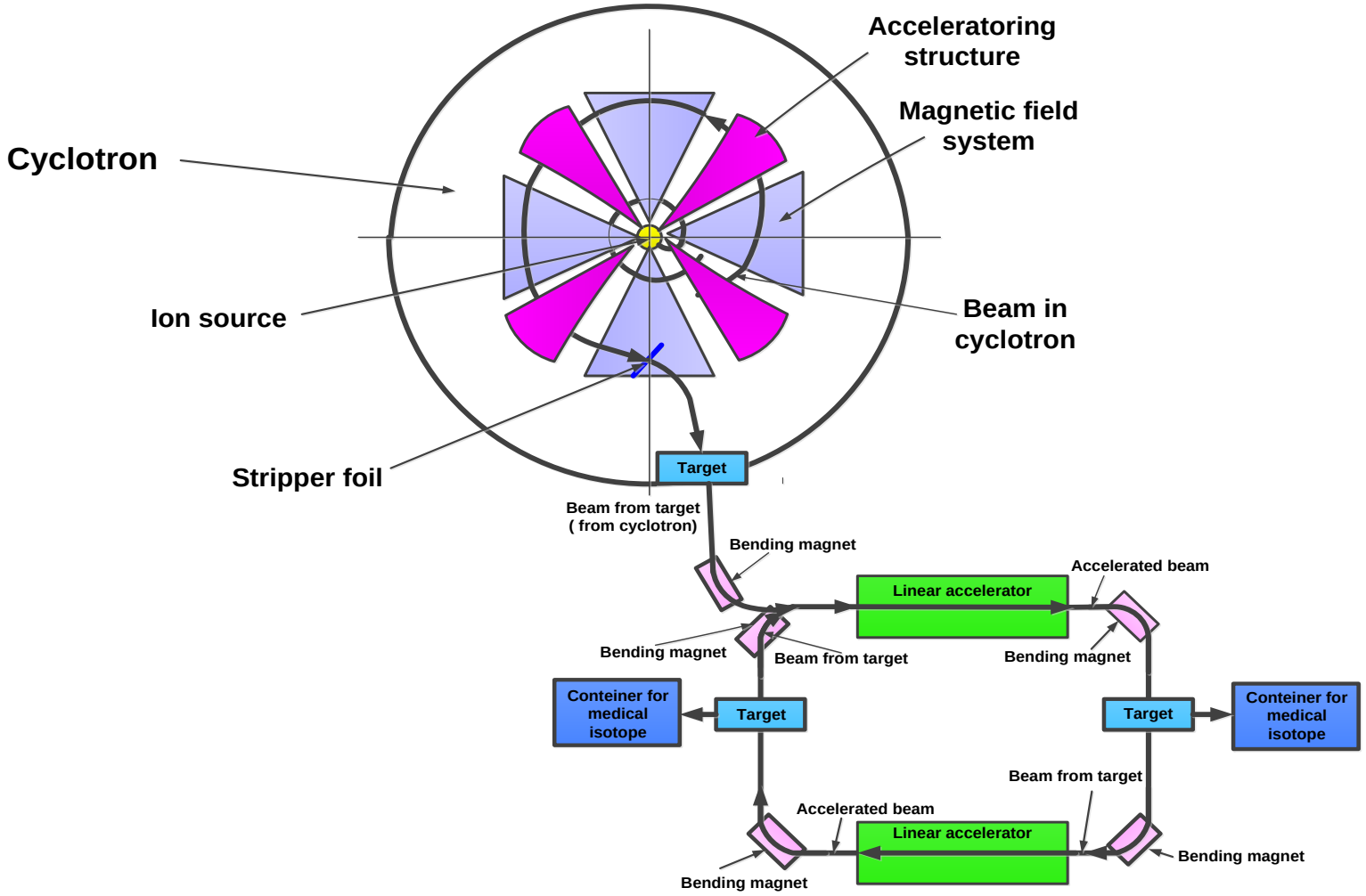


Accelerator System
Multiple stages of acceleration

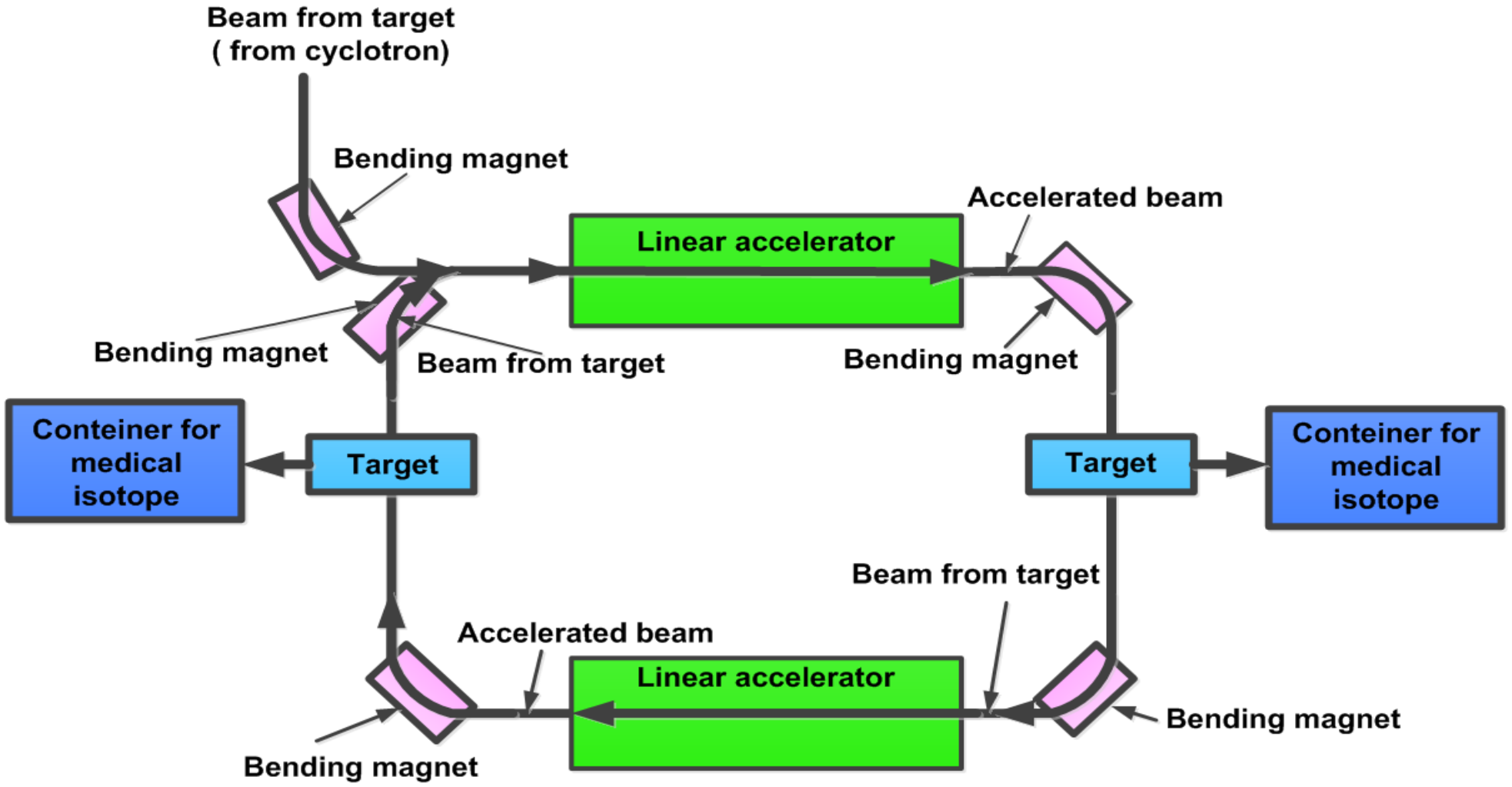


Accelerator System with Cyclotron

Cyclotron is used as injector



Multi-Stage Accelerator System



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Main Parameters of Accelerator System

1. Kinetic energy of beam from injector (cyclotron): 11-18 MeV
2. Beam current of beam from injector (cyclotron): 100-500 μA
3. Kinetic energy of beam after targets: 5-6 MeV
4. Kinetic energy of beam from accelerating structures: (5-6) to (11-18) MeV
5. Total yield of 3 targets for each beam from cyclotron with 3.5 Ci: (11.5-12) Ci

Accelerating Structures

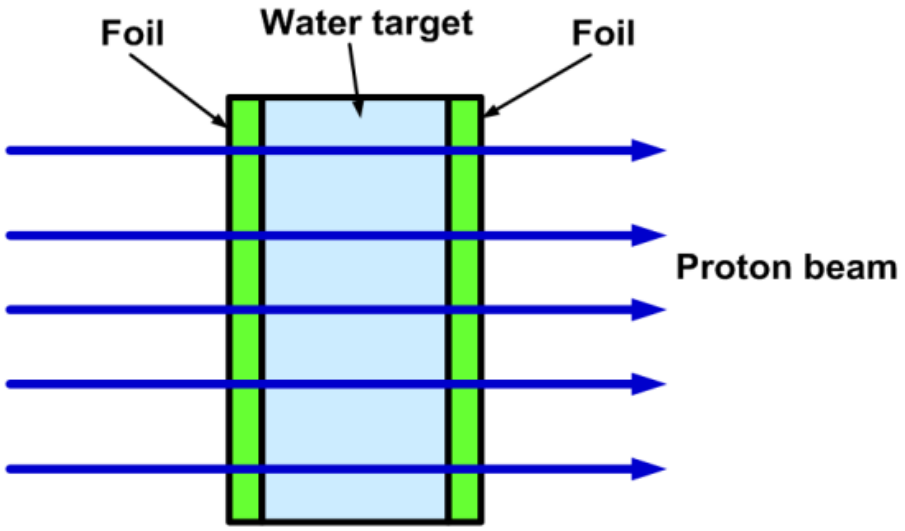
- DC structure
- RF structure
- RF superconducting structure

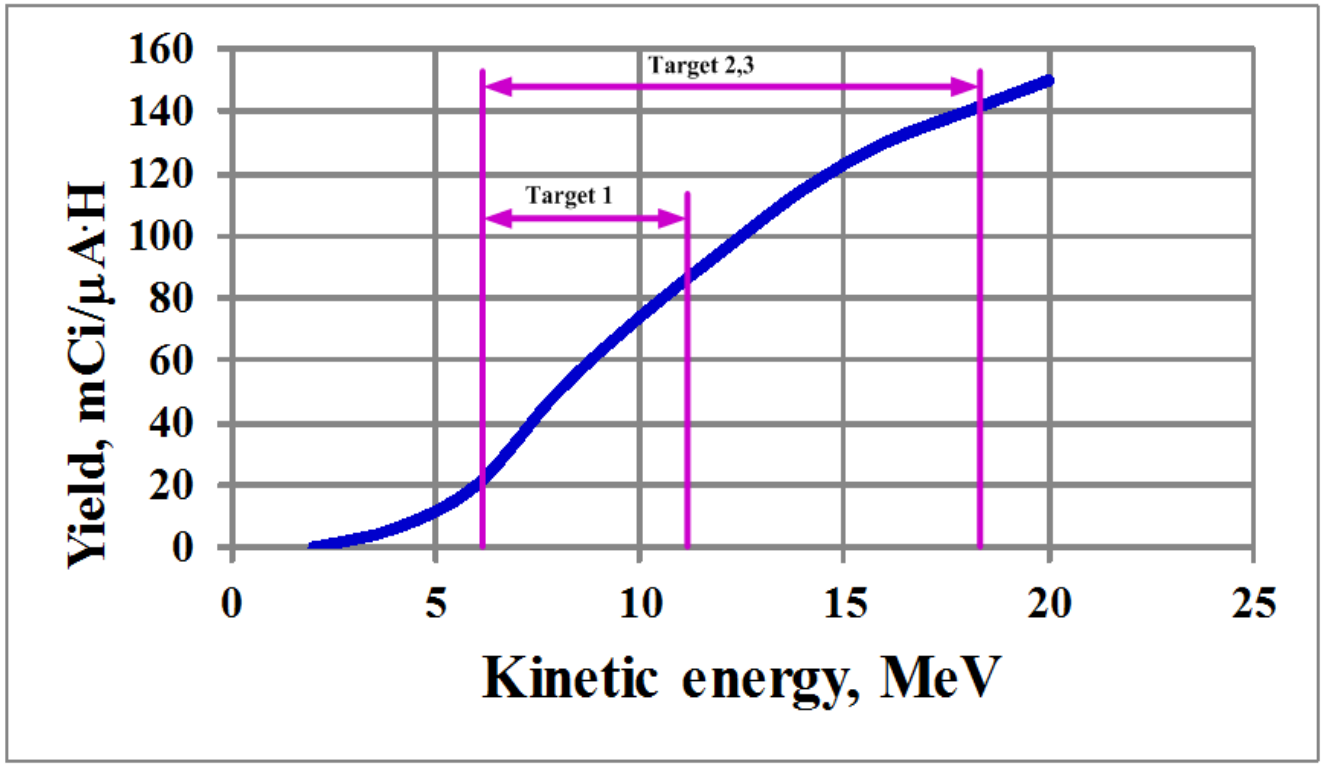
- More effective accelerating structure is the RF superconducting structure with a gradient of accelerating electrical field ~ (25-33) MV/m[4]
- Variant of racetrack FFAG accelerator was considered on the International Cyclotron Conference in Vancouver 2013[5]

4 Source: I. Gonin, M. Champion, T. Khabiboulline, A. Lunin, N. Perunov, N. Solyak, V. Yakovlev, "Single Spoke Cavities For Low-Energy Part Of CW LINAC of PROJECT X", FERMILAB-CONF-10-423-TD
5 Source:C. Jonstone, M. Bers, K.Makine, P. Snopok. "A Compact, GEV, High-Intensity (CW) Racetrack FFAF", MOPPT019

Target Concept

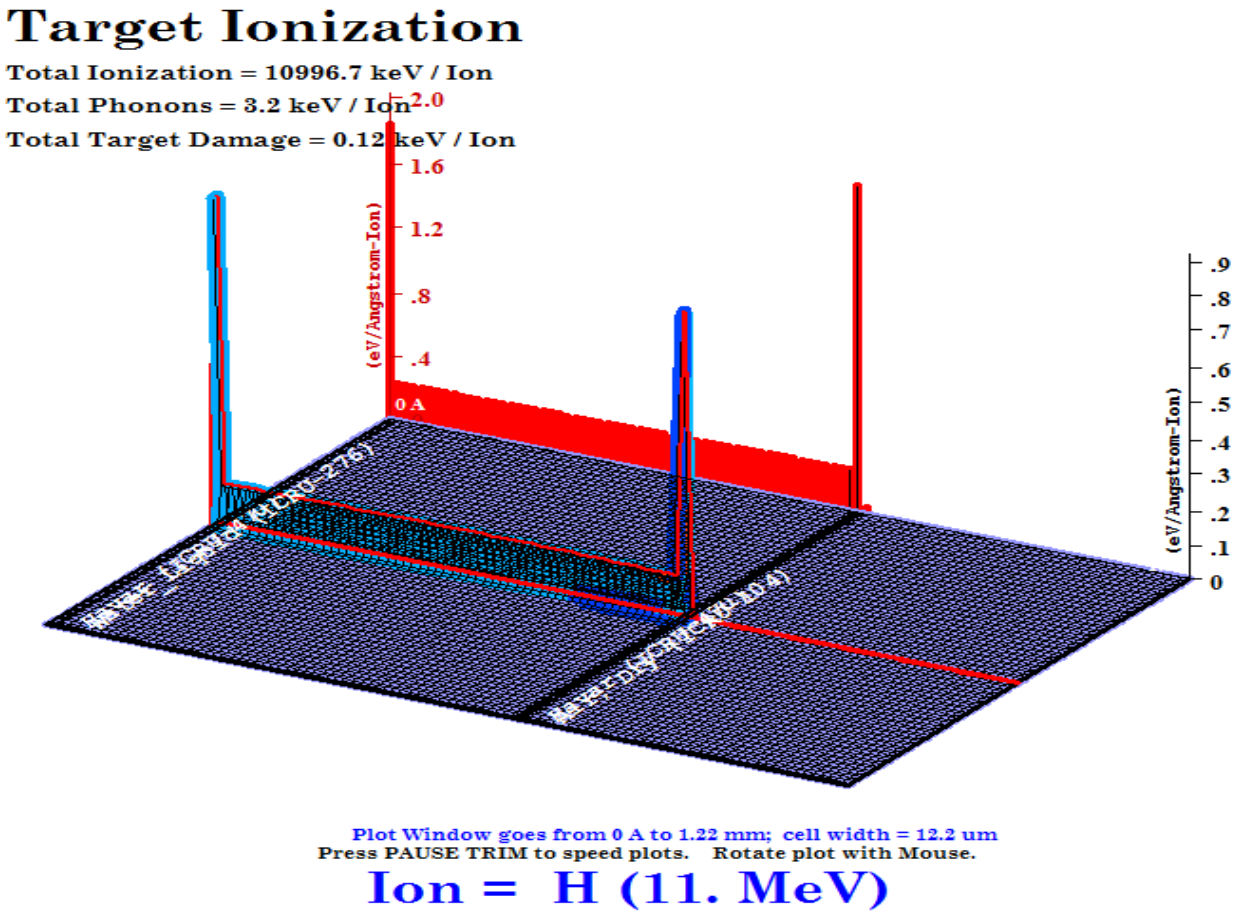
- Partial use of an electron beam in the irradiated material was published at the EPAC 2008 [6]

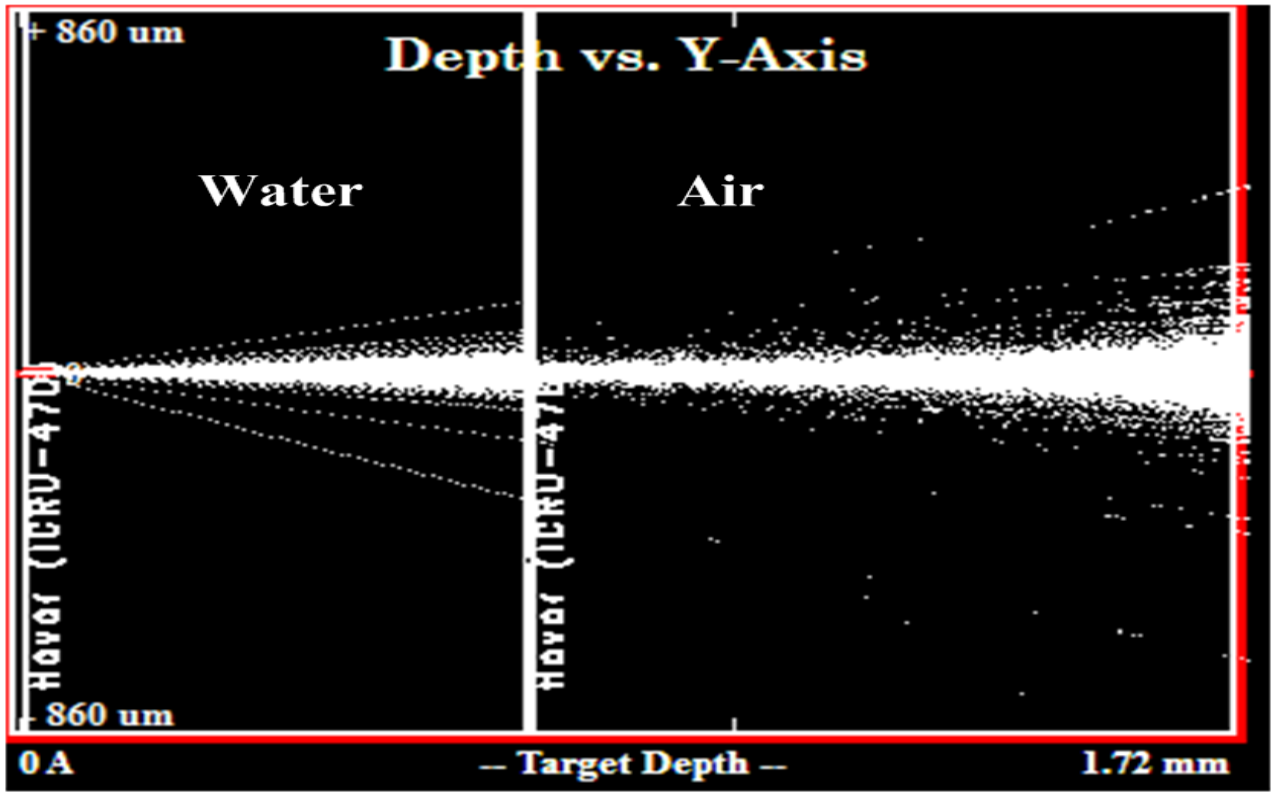




6 Source: S. Korenev, R. Johnson. "Electron Accelerator for Cleaning of Flue Gases and Oil Liquefaction", European Accelerator Conference 2008, Italy, 2008

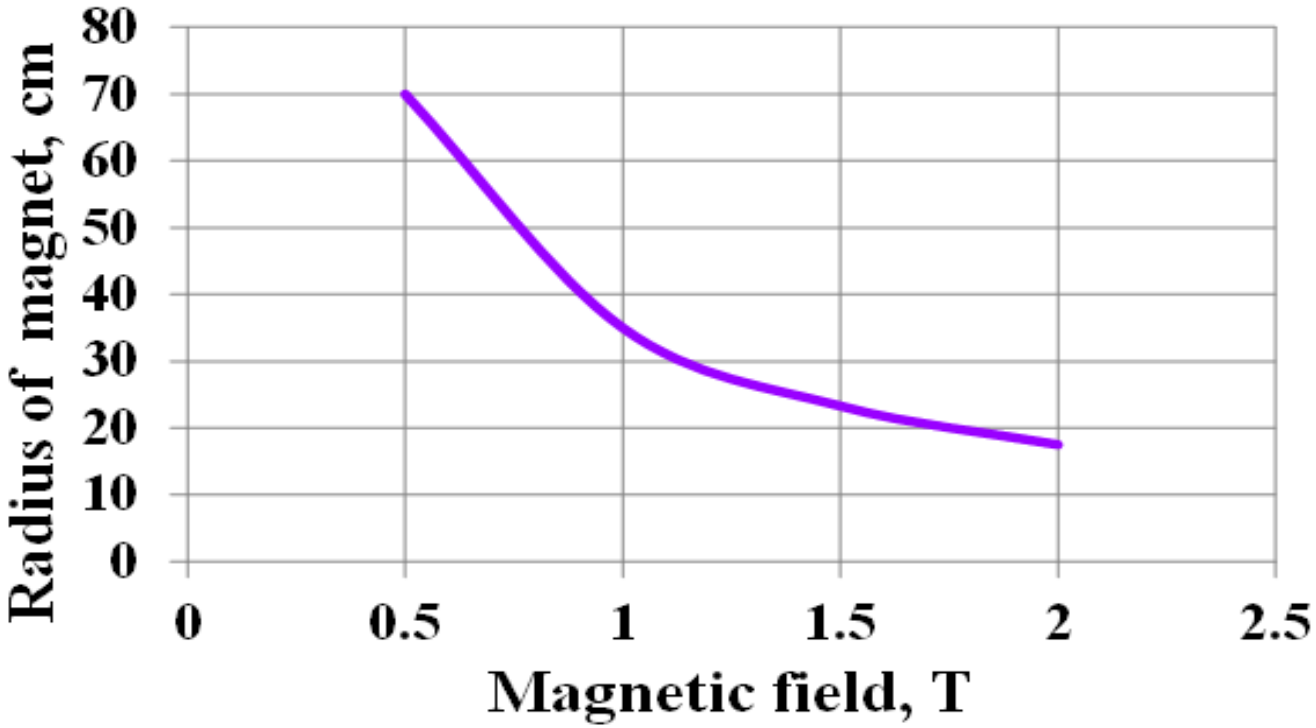
Ionization in Target and Propagation of Proton Beam



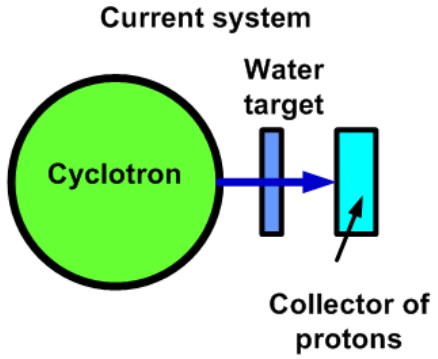


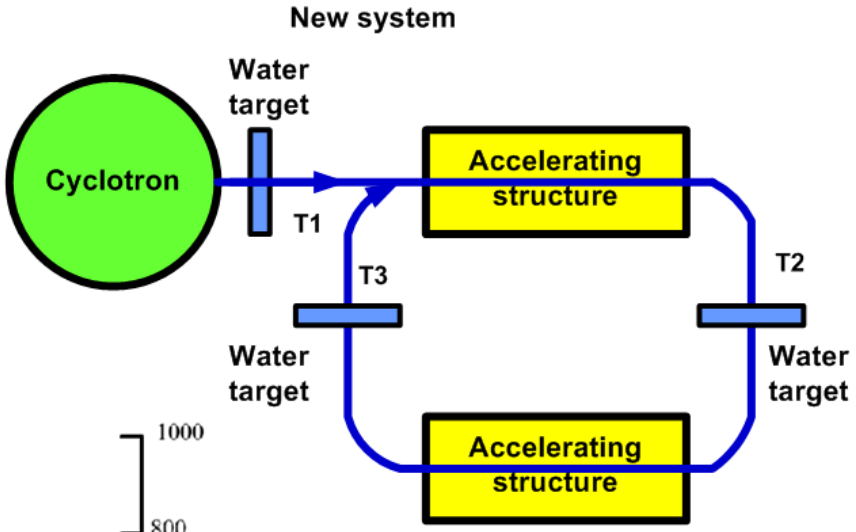
Bending Magnet

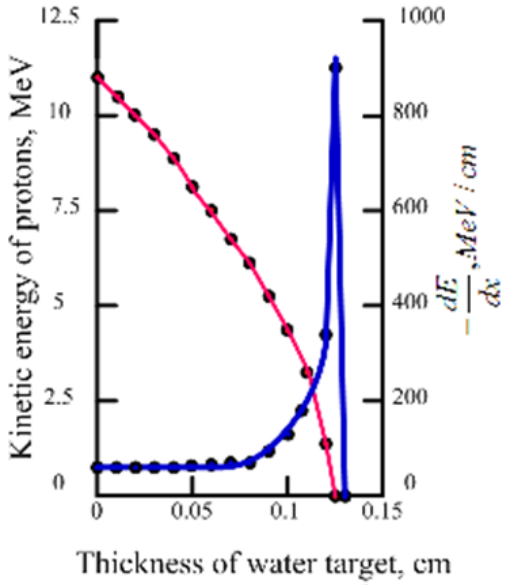
- The bending magnet will utilize a standard magnet
- The radius of the bending magnet for a proton beam with a kinetic energy of 6 MeV is simple for engineering design

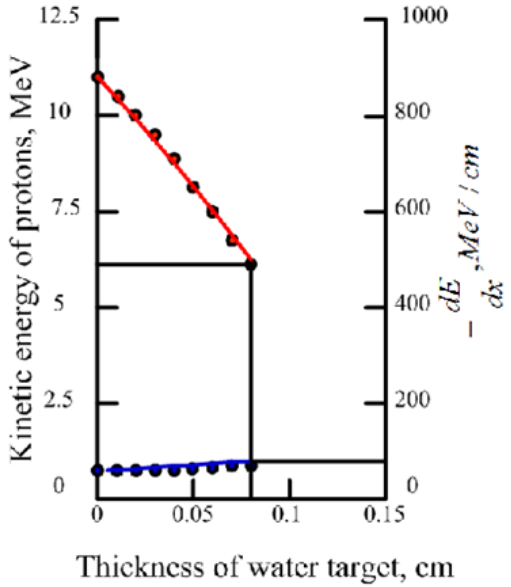


Comparison of the Two Accelerator Systems









Parameter	Current system	New system
Beam efficiency	50-60%	90-95%
Average activity of ^{18}F to end of irradiation (2 hours)	3.5 Ci	(11.5-12)Ci

Conclusion

- The new concept of this accelerator system allows for a significant increase in Fluorine-18 (^{18}F) production within the fixed energy Eclipse cyclotron

- The detail physical analysis of sub-systems for the accelerator system is required

Thank you!

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