Production of Radioisotopes from D-^{3}He Fusion Devices

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Objectives:

- Develop a gaseous target for the production of PET radioisotopes from an isotopic source of 14.7 MeV D-^{3}He fusion protons
- Evaluate gaseous target performance in combination with an Inertial Electrostatic Confinement (IEC) fusion device
- Determine required D-^{3}He fusion rates for medically usable quantities of ^{11}C

Medical Imaging:

Positron Emission Tomography (PET)

- PET is a current medical technique used to image abnormalities and dynamic processes inside the body
- Shorter half-life isotopes reduce the dose to high risk patients, but requires isotope production be within close proximity to the patient

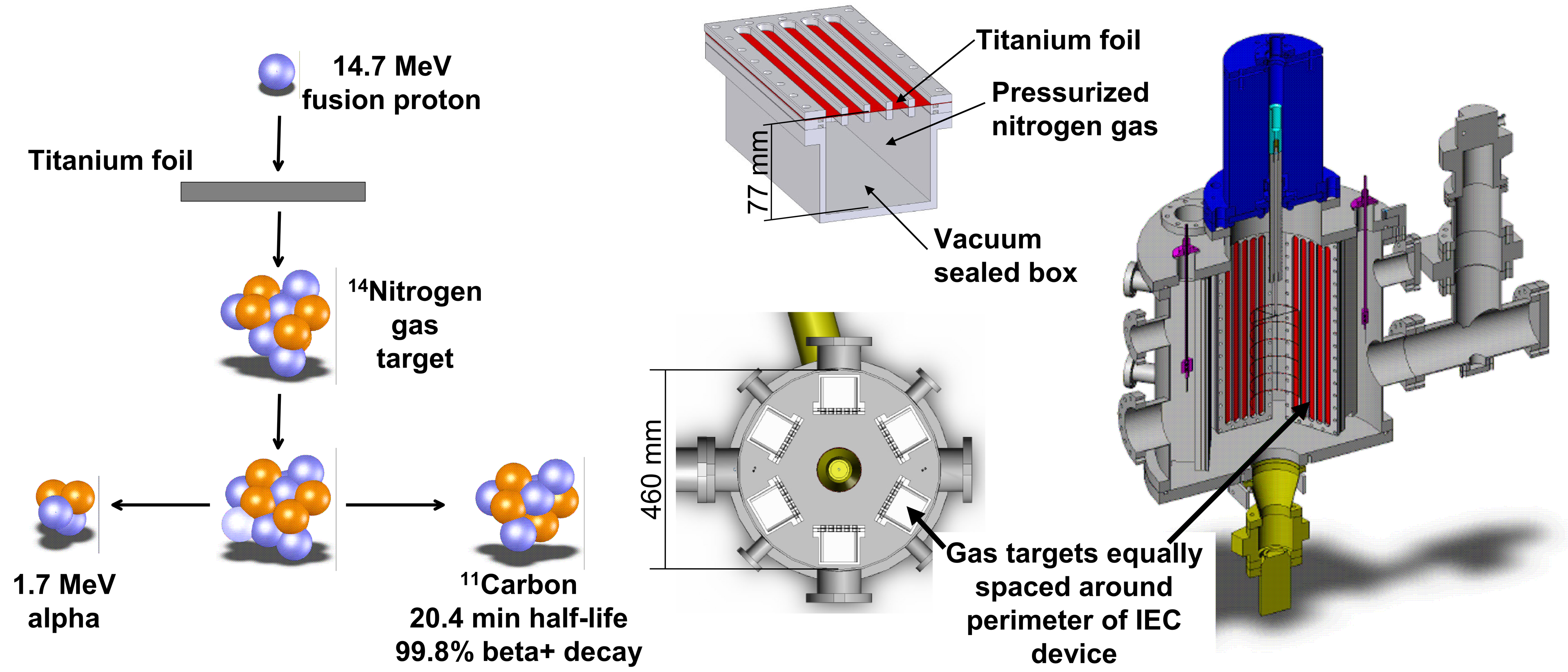
Properties of Common Radioisotopes for PET[1]

Isotope	Production Reaction	Isotope Half-life	Maximum β^+ Energy	Radiopharmaceutical compounds	Approximate Dosage
^{11}C	$^{14}N(p,\alpha)^{11}C$ $^{10}B(d,n)^{11}C$ $^{11}B(p,n)^{11}C$	20.4 min	960 keV	Carbon dioxide Hydrogem cyanide Methane	2-10 mCi (74-370 MBq)
^{13}N	$^{16}O(p,\alpha)^{13}N$ $^{12}C(d,n)^{13}N$	9.97 min	1.19 MeV	Ammonia Nitrogen oxide	10-15 mCi (370-555 MBq)
^{15}O	$^{15}N(p,n)^{15}O$ $^{14}N(d,n)^{15}O$	2.05 min	1.72 MeV	Water Carbon dioxide	1 mCi (37 MBq)
^{18}F	$^{18}O(p,n)^{18}F$ $^{20}Ne(d,\alpha)^{18}F$	109.8 min	635 keV	Fluorodeoxyglucose Fluoridic acid	2-10 mCi (74-370 MBq)

1. A. OWUNWANNE, M. PATEL, and S. SADEK (1995). The handbook of radiopharmaceuticals. London New York: Chapman & Hall Medical

Concept:

- Multiple pressurized gas targets surround an isotropic source of 14.7 MeV protons
- D-^{3}He fusion produced by an Inertial Electrostatic Confinement (IEC) device
- A low atomic number metal used to separate the gas from vacuum



Proof of Concept:

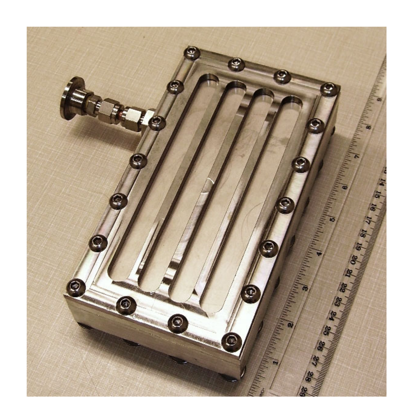
Previous Work Using Different Target Designs

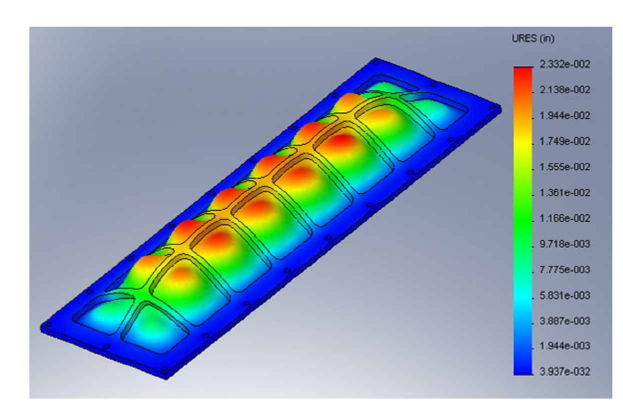
- Weidner-2003 produced 0.20 nCi of ^{13}N with 7.5×10^6 p/s in the UW IEC device in a water-filled tube radiator type device [2]
- Cipiti-2004 in independent experiments produced 1.0 nCi of ^{13}N at 4×10^6 p/s and 1.5 nCi of ^{94m}Tc at the UW IEC facility [3]

2. J.W. WEIDNER, (2003). The production of N-13 from inertial electrostatic confinement fusion. (M.S. dissertation, University of Wisconsin - Madison).
3. B.B. CIPITI, (2004). The fusion of advanced fuels to produce medical isotopes using inertial electrostatic confinement. (Doctoral dissertation, University of Wisconsin - Madison).

Mechanical Strength:

Testing and Simulation

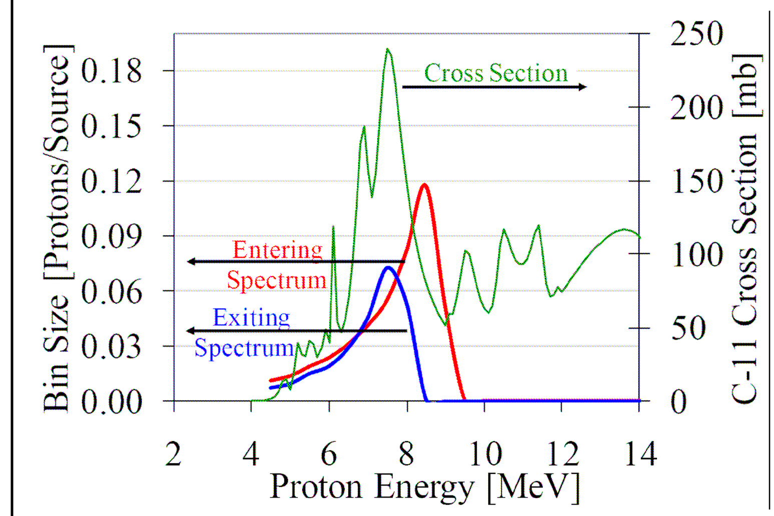




- Titanium chosen as a balance of low proton attenuation and high mechanical strength
- Baseline design (0.5 mm Ti, 4 atm) had a calculated safety factor of 2
- Small prototype tested to 7 atm

Activation Simulation:

MCNPX 2.5.0 Results for ^{11}C

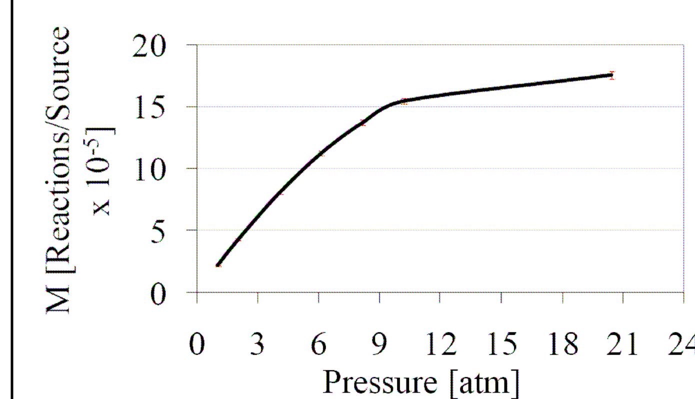


Proton spectrum entering the gas (after Ti foil) and exiting the gas (after Ti and gas) for baseline case of 0.5 mm Ti foil, 4 atm of pure ^{14}N gas, and 77.5 mm target depth compared to $^{14}N(p,\alpha)^{11}C$ cross-section

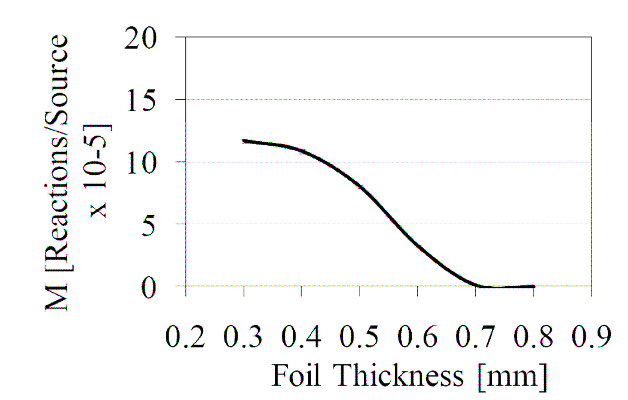
Optimization of foil thickness and gas pressure / target depth

$$A(t) = (M \cdot S) \cdot (1 - e^{-\lambda t})$$

M is Multiplication factor, A is activity [Bq]
S is assumed isotropic source strength [p/s]
λ is the decay constant [sec^{-1}], t is time [sec]

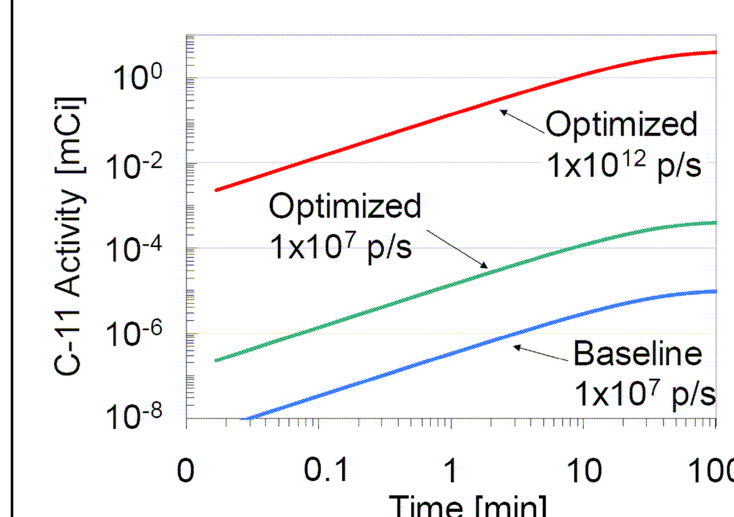


Multiplication factor, M, versus pressure with Ti foil thickness held at 0.5 mm and target depth at 77.5 mm



Multiplication factor, M, versus Ti foil thickness with the pressure held at 4 atm and target depth at 77.5 mm

^{11}C Activity at Various Fusion Rates and Optimized Ti Foil and Gas Pressure



Activity of ^{11}C as a function of irradiation time for baseline case at present laboratory scale IEC fusion rates, present rates for optimized case (0.3 mm Ti, 10 atm gas), and optimized case to reach 1mCi of activation

Conclusions:

- 400 nCi of ^{11}C is achievable at present laboratory scale IEC fusion rates
- A D-^{3}He fusion rate of approximate 1×10^{12} p/s would activate1 mCi of ^{11}C