Realizing the Benefits of Fusion Energy in Our Lifetime

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Why Are We Concerned About the Timetable for Demonstrating Benefits from Fusion Energy?

- Commercial electricity from fusion is now perceived as being 50 years or more away
- Developing the first fusion reactor is a 20$B+ program
- Keeping Americans' attention on a multi-billion, multi-decade project will be difficult

What Can We Do to Demonstrate Benefits from Fusing Plasmas on a Much Shorter Timeframe (≈5-10 years) and for Much Less Money (<<100 $M)?
In the Near Term (where $Q<<1$), What Does the Fusion Community Have to Sell That is Unique?

- **Portable Source of Neutrons**
  
  Non-proliferating technology,
  No fission products,
  Small source possible (few watts fusion power),
  Thermal to 14 MeV Energy

- **Portable Source of Protons**
  
  Up to 14 MeV Energy
  Little auxiliary radioactivity
  Competes with accelerators or cyclotrons

- **Portable Source of Electromagnetic Radiation**
### There are Several Useful High Energy Particles from the Most Promising Fusion Reaction

<table>
<thead>
<tr>
<th>Reaction</th>
<th>neutrons (MeV)</th>
<th>protons (MeV)</th>
<th>Helium atoms (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT</td>
<td>$3.6 \times 10^{11} \ (14.1)$</td>
<td>--</td>
<td>$3.6 \times 10^{11} \ (3.52)$</td>
</tr>
<tr>
<td>DD</td>
<td>$8.6 \times 10^{11} \ (2.45)$</td>
<td>$8.6 \times 10^{11} \ (3.01)$</td>
<td>--</td>
</tr>
<tr>
<td>$^3\text{He}^3\text{He}$</td>
<td>$5.3 \times 10^{10} \ (2.45)$</td>
<td>$3.4 \times 10^{11} \ (14.7)$</td>
<td>$3.4 \times 10^{11} \ (^4\text{He}, \ 3.67)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$4.4 \times 10^{10} \ (3.01)$</td>
<td>$5.3 \times 10^{10} \ (^3\text{He}, \ 0.82)$</td>
</tr>
<tr>
<td>$^3\text{He}^3\text{He}$</td>
<td>--</td>
<td>$9.7 \times 10^{11} \ (~5.7)$</td>
<td>$4.9 \times 10^{11} \ (1.4)$</td>
</tr>
<tr>
<td>$^1\text{p}^1\text{B}$</td>
<td>--</td>
<td>--</td>
<td>$2.2 \times 10^{12} \ (2.9)$</td>
</tr>
</tbody>
</table>
### Potential Non-Electric Commercial Opportunities Associated with the Long Range Development of Fusion Electrical Power

<table>
<thead>
<tr>
<th>Near Term</th>
<th>Intermediate Term</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Medical</strong></td>
<td><strong>Civilian</strong></td>
</tr>
<tr>
<td>– Isotope Production</td>
<td>– Positron Emitter Production</td>
</tr>
<tr>
<td>– Cancer Therapy</td>
<td>– Proton Activation Analysis</td>
</tr>
<tr>
<td><strong>Commercial</strong></td>
<td><strong>Commercial</strong></td>
</tr>
<tr>
<td>– Positron Emitter Production</td>
<td>– Gemstone Enhancement</td>
</tr>
<tr>
<td>– Proton Activation Analysis</td>
<td>– Neutron Radiography</td>
</tr>
<tr>
<td>– Gemstone Enhancement</td>
<td>– Production of Tritium</td>
</tr>
<tr>
<td>– Neutron Radiography</td>
<td>– Neutron Irradiation Facility</td>
</tr>
<tr>
<td><strong>Environmental</strong></td>
<td><strong>Environmental</strong></td>
</tr>
<tr>
<td>– Detection of Chemical Spills</td>
<td>– Production of Hydrogen</td>
</tr>
<tr>
<td><strong>Defense</strong></td>
<td><strong>Defense</strong></td>
</tr>
<tr>
<td>– Detection of Explosives</td>
<td>– Destruction of Fission Products</td>
</tr>
<tr>
<td>– Detection of Chemical Weapons</td>
<td>– Destruction of Pu &amp; Actinides</td>
</tr>
<tr>
<td></td>
<td>– Production of Tritium</td>
</tr>
</tbody>
</table>
What Use Can Society Make of Small, Compact (Q<1) Fusion Neutron or Proton Sources?

<table>
<thead>
<tr>
<th>Neutron Applications</th>
<th>PET Isotopes</th>
<th>Isotopes</th>
<th>Proton Applications</th>
<th>PET Isotopes</th>
<th>Isotopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection of Clandestine Materials</td>
<td>99mTc</td>
<td>Destruction of Fission Waste</td>
<td>PET Isotopes - $^{15}$O, $^{11}$C, $^{13}$N</td>
<td>PET Isotopes- $^{18}$F</td>
<td>Destruction of Long Lived Radioisotopes</td>
</tr>
<tr>
<td>Trace Elements</td>
<td>$^{99}$Mo</td>
<td>Tritium Production</td>
<td>Isotopes- $^{99m}$Tc</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fusion Power Level</th>
<th>1–10 Watts</th>
<th>10 – 1000 W</th>
<th>1 – 100 kW</th>
<th>10 – 1000 MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>nearer term</td>
<td>nearer term</td>
<td>nearer term</td>
<td>nearer term</td>
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</tr>
</tbody>
</table>
Small Mobile PET Generators Could Reduce Radiation Exposure to Patients

- Presently $^{18}$F ($t_{1/2} = 1.83$ h) is used extensively for brain scans.
- Current regulations preclude the repeated use of $^{18}$F on young children and pregnant women.
- An ideal PET isotope would be $^{15}$O ($t_{1/2} = 2.03$ min).
- 1 Watt of D$_3$He fusion could produce $\approx 8$ mCi of $^{15}$O (steady state).

![Graph of Integrated $(p,n_0)$ Cross Section](image)
The $^{18}\text{O}(p,n)^{18}\text{F}$ Cross Section Peaks Between 5–6 MeV

Source: T.J. Ruth and A.P. Wolf
The $^{100}$Mo(p,2n)$^{99m}$Tc Cross Section Peaks at the Energy of the D\textsuperscript{3}He Proton

Ref: V. N. Levkovskij
Record Steady State D-\(^3\)He Reaction Rate Achieved in Wisconsin IEC Device

\[ 1.5 \times 10^5 \text{ protons/s (14.7 MeV)} \]
Record Steady State D-D Reaction Rate
Achieved in Wisconsin IEC Device

$2.2 \times 10^7$ neutrons/s (2.45 MeV)
Radioisotopes Particularly Suited For Production With Protons From D-\(^3\)He Fusion

<table>
<thead>
<tr>
<th>Isotope</th>
<th>(t_{1/2})</th>
<th>Parent Isotope</th>
<th>Maximum Steady State Production at Equilibrium (mCi/watt D-(^3)He)</th>
<th>Useful Dose (mCi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{15})O</td>
<td>2.03 m</td>
<td>(^{15})N</td>
<td>8</td>
<td>(~ 1)</td>
</tr>
<tr>
<td>(^{18})F</td>
<td>1.83 h</td>
<td>(^{18})O</td>
<td>14</td>
<td>1 – 10</td>
</tr>
<tr>
<td>(^{99m})Tc</td>
<td>6.01 h</td>
<td>(^{100})Mo</td>
<td>4</td>
<td>1 – 25</td>
</tr>
</tbody>
</table>
Conclusions

• The U.S. fusion program could have a positive near term impact on the production of very short half life PET isotopes for applications in hospitals.

• Research into advanced fuel, very low Q fusion devices, is relatively inexpensive and could contribute to our understanding of the long-range potential of the "second generation" fusion fuels.