An Extremely High $I_{sp}$ Spacecraft Propulsion System

L. P. Forsley (GEC, NASA),
*Deputy PI, NASA LCF Project*

T. L. Benyo, Ph.D. (NASA),
*PI, NASA LCF Project*

P. A. Mosier-Boss, Ph.D. (GEC),
*Senior Scientist*

L. A. Dudzinski (NASA),
*Chief Technologist, Planetary Science Division*
Lattice Confinement Fusion (LCF)\(^1\)

### Measured Nuclear Reactions:
NASA JSC Linear Energy Transfer Analysis of Solid State Nuclear Track Detectors (CR-39) from two experiments\(^2,3\) at SRI.

\[ \text{e.g.} \]

\[ ^7\text{Li}(d,n)2\alpha \] 3-body nuclear reaction

### Proposed Application:
Lattice Confinement Fusion reaction charged products for high \(I_{sp}\) propulsion:
- \(D(^3\text{He},p)\alpha > 14.8\) MeV proton, 3.4 MeV \(\alpha\)
- \(\text{Pd}(d,n)p > 6\) MeV proton
- \(^7\text{Li}(p,\alpha)\alpha > 2\) \(8.5\) MeV \(\alpha\)

### LCF: Triggered fusion in electron-screened, high-density deuterated metal lattices.

---


Specific Impulse
It’s all about the exhaust velocity!

- Specific Impulse is a measure of rocket engine efficiency expressed in seconds
  \[ I_{sp} = \frac{v_e}{g_o} \]
  where \( v_e \) is the propellent exhaust velocity in m/s, \( g_o = 9.8 \) m/s²

<table>
<thead>
<tr>
<th>Propulsion</th>
<th>Exhaust Velocity (( v_e ))</th>
<th>Specific Impulse (( I_{sp} ))</th>
<th>Thrust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>( v_e &lt; 4.4 \times 10^3 ) m/s</td>
<td>&lt; ( 4.5 \times 10^2 ) s</td>
<td>High</td>
</tr>
<tr>
<td>Nuclear Thermal</td>
<td>( v_e \approx 9.0 \times 10^3 ) m/s</td>
<td>( \approx 9.0 \times 10^2 ) s</td>
<td>High</td>
</tr>
<tr>
<td>Solar Electric</td>
<td>( v_e \approx 2.9 \times 10^4 ) m/s</td>
<td>( \approx 3.0 \times 10^3 ) s</td>
<td>Low</td>
</tr>
<tr>
<td>VASIMR(^{1,2})</td>
<td>( v_e \approx 1.2 \times 10^5 ) m/s</td>
<td>( \approx 1.2 \times 10^4 ) s</td>
<td>Variable</td>
</tr>
<tr>
<td>Nuclear Fusion(^3)</td>
<td>( v_e \approx 3.5 \times 10^5 ) m/s</td>
<td>( \approx 3.5 \times 10^4 ) s</td>
<td>High</td>
</tr>
<tr>
<td>LCF</td>
<td>( v_e &gt; 1.5 \times 10^7 ) m/s</td>
<td>&gt; ( 1.5 \times 10^6 ) s</td>
<td>Variable</td>
</tr>
</tbody>
</table>

**High \( I_{sp} \) usually means low thrust, but with nearly continuous acceleration!**

2. VASIMR\(^\circledast\): Variable Specific Magnetoplasma Rocket
An Extremely High Isp Propulsion System

- Alpha particles > 6 MeV have exhaust velocities approaching 5% speed of light!
  - $c = 3 \times 10^8$ m/sec (speed of light in vacuum)
  - $v_e > 1.5 \times 10^7$ m/sec (propellent exhaust velocity)
  - $I_{sp} > 10^6$ sec

- $\approx 10,000$ times chemical rocket $I_{sp}$
- $\approx 1000$ times Solar Electric Propulsion (SEP) ion thruster $I_{sp}$
- $\approx 100$ times VASIMR® $I_{sp}$

- Charged particles can be directed by magnetic and electric fields
- Magnetohydrodynamics (MHD) can be used to power the spacecraft with a loss of $I_{sp}$
- LCF is an inherently low thrust system, but offers continuous acceleration like SEP
  - Thrust can be traded off against $I_{sp}$ by heating and expelling heavier mass