D-T Pellet Injection for ITER Plasma Fueling

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US ITER Fusion Integration

Tritium Working Group
Y-12 Facility
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ITER Tokamak Complex
ITER Construction Site
ITER Fueling Requirements are a Significant Challenge

- ITER plasma volume is **840 m³**
- Plasma Density > **1 x 10²⁰ m⁻³** with D-T in order to optimize the fusion gain (Q=10)
- Gas fueling will be limited by poor neutral penetration (<1% fueling efficiency)
- **Pellet injection from the inner wall** provides for deep fueling and high fueling efficiency
- ITER requires **high D-T mass flow for up to 1 hour plasma duration with high reliability**
- Fusion burn fraction is small ~ 1%, thus **high fueling rate** is required and **fuel must be re-circulated**
Cryogenic D2 Pellet in an ASDEX Plasma (1982)

Photo provided by P. T. Lang and K. Büchl (IPP, ASDEX)

0.1 ms Framing Time

~1.8 mm diameter (L/D=1)

Pellet velocity 800 m/s
## ITER Pellet Fueling Requirements & Pellet Injector Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma density ( &lt;n&gt; )</td>
<td>( 0.5 - 1.2 \times 10^{20} \text{ m}^{-3} )</td>
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<tr>
<td>Fuel isotope (pellet)</td>
<td>( \text{H}_2, \text{D}_2, \text{D}-\text{T}, \text{T}_2 ) (90% T/10% D)</td>
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<tr>
<td>Maximum pellet fueling rate</td>
<td>( \text{H}_2, \text{D}_2, \text{D}-\text{T}, \text{T}_2 ) (90% T/10% D)  ( 120 \text{ Pa-m}^3/\text{s} ) (~1000 torr-L/s) ( 110 \text{ Pa-m}^3/\text{s} ) ( 10 \text{ Pa-m}^3/\text{s} )</td>
</tr>
<tr>
<td>Impurity</td>
<td></td>
</tr>
<tr>
<td>Pulse length</td>
<td>3000 s</td>
</tr>
<tr>
<td>Pellet size (nominal)</td>
<td>( 3 \text{ and } 5 \text{ mm diameter} ) ( 1.25 \text{ and } 6 \times 10^{20} \text{ atoms} ) ( \Delta n/n \sim 1.3% \text{ and } 6.6% )</td>
</tr>
<tr>
<td>Maximum injection frequency</td>
<td></td>
</tr>
<tr>
<td>Core fueling</td>
<td>4 Hz</td>
</tr>
<tr>
<td>ELM triggering</td>
<td>16 Hz</td>
</tr>
<tr>
<td>Impurity injection</td>
<td>5 pellets</td>
</tr>
<tr>
<td>Pellet speed</td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>300 m/s</td>
</tr>
<tr>
<td>Maximum</td>
<td>500 m/s</td>
</tr>
<tr>
<td>Number of injectors</td>
<td>2 initially (up to 6 for D-T phase)</td>
</tr>
</tbody>
</table>
Tritium pellets have previously been formed and accelerated at LANL Tritium Systems Test Assembly (TSTA)
ITER Pellet Injectors and Containment Casks

Pellet guide tubes enter through the vacuum pumping ducts and are mounted to the inner surface of the vacuum vessel.

Pellet Injectors at three toroidal locations at Building Level B1

Pellet Injector subsystems are housed in tritium containment casks.
Pellet Injection Process Flow

Development of pellet injection subsystem equipment inside the cask is ongoing
Integrated Pellet Injection Subsystems inside the cask

- Cryogenic DT ice extruder and nozzle
- DT Fuel Recirculation Loop
- Pellet cutter and high pressure gas gun
- Pellet guide tube selector
- Propellant Recirculation Loop
- Tritium compatible piston vacuum pump
- Containment cask
Pellet Injection Process Flow

- D₂/T₂ Gas: ~0.9 bar(a), 300K
  - Flow: 240 Pa.m³/s (Avg Flow Both Lines.)
- N₂ Purge Gas
- D₂ Gas: ~0.9 bar(a) Propellant Makeup
- Propellant Makeup: 40 bar
- Cutter/Valve
- Vacuum
- Tank <10 mbar
- Piston Pump
- Frozen D-T Fuel Extruders
- D₂/T₂ Pellets to Plasma: 240 Pa.m³/s (Max.) Total D₂+T₂ 111 Pa.m³/s T₂ (Max.)

- Pellet Injection Cask: ~0.05 bar(g)
  - Composition: >99% N₂, <1.0% O₂
  - Vent to Detritiation System
  - Volume: ~46 m³
Pellet Injection Hardware Prototypes

D-T ice cooler and twin screw extruder assembly

15 K D ice ribbon below extruder nozzle

Unused ice sublimes and is recycled within PI system
Dual nozzle, cutter and gun sub-assembly
Pellet Injection Hardware Prototypes

Dual nozzle, cutter and gun sub-assembly
Injector Assembly
Located inside Cryostat.
Pellet Injection Hardware Prototypes

Guide tube mockup for speed limit determination

Guide tube selector
Pellet Injection Process Flow

Pellet Injection Cask
~0.05 bar(g)
>99% N₂, <1.0% O₂
Vented to Detritiation System
Vol. ~46 m³

D₂/T₂ Pellets to Plasma
240 Pa.m³/s (Max.) Total D₂+T₂
111 Pa.m³/s T₂ (Max.)

Propellant Recirculation

Piston vacuum pump
Pellet Injection Hardware Prototypes

Tritium Compatible Piston Pump

- Operated for nearly 15,000 hours over multiple years without significant performance degradation.
- No-load pressures between 0.1 Torr and 0.2 Torr
- Pumping speeds of 150 m3/h at suction pressure of 10 Torr.
- Pump operation stopped when noise developed within the pump housing.
- Disassembly found immovable tension rings within the outer grooves of the upper piston and broken Vespel rings.
- Did not significantly degrade performance, but design improvement in these two areas could lead to longer operating periods and higher availability.