Spatial and Energy Profiling of D-D Fusion Reactions in an IEC Fusion Device

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Outline

• Fusion Ion Doppler (FIDO) Diagnostic
  – Energy Profiling Results
• Time of Flight (TOF) Diagnostic
  – Preliminary Spatial Profiling Results
All experiments discussed here conducted on UW IEC chamber known as HOMER

- **Cylindrical Aluminum Chamber**
  - **Diameter**: 91 cm
  - **Height**: 65 cm

- **Feed Gas**: Deuterium

- **Typical Operating Parameters**
  - **Pressure**: 1.5 - 2.5 mTorr
  - **Voltage**: 40 – 160 kV
  - **Current**: 30 – 60 mA
• **Goal** – Examine the Doppler Shift imparted to D(d,p)T fusion products by the deuterium reactants to unfold the deuterium energy spectrum within HOMER IEC device.

• **Problem** – X-ray noise overwhelms triton (1.01 MeV) peak and clouds proton (3.02 MeV) peak making Doppler Shift unreliable to read.

• **Solution** – Move charged particle detectors out of line of sight of chamber.

• **Results** – The line averaged energy spectrum of deuterium ions and fast neutrals obtained over a wide range of parameter space within the HOMER IEC device.
Solution to Minimizing X-Ray Noise

- Detector face moved out of line of sight of chamber
- Magnetic Deflection
  - Fusion products (MeV)
  - Secondary electrons (Hundreds of keV)

- Pb shielding around collimator channel and detector mount
Collimator channel has a ~20 degree bend at the elbow taking detector out of line of sight of chamber.

**Fusion Ion Doppler (FIDO) Diagnostic**

- Detector Face
- Fusion Products
- 1.5 T Electromagnet
New setup allows both protons and tritons to be detected

Raw Data from Charged Particle Detector (60kV 45mA 1.5mtorr)

Current X-ray Noise with Bending Arm and without Pb shield

Previous scale of X-ray noise without Bending Arm and with Pb shield

Doppler Shifted D-D triton peak

Doppler Shifted D-D proton peak
Subtraction of X-ray noise reveals proton & triton peaks of comparable size.

70kV 30mA 1.25mtorr

Examine either side of the double peaked spectra to yield center of mass energy of the deuterium reactants.
Calculating the Deuterium Energy Distribution

- Scaling the number of counts in each energy bin from the previous data set by $\sigma_{\text{fusion}}(E_{\text{bin}})$ and normalizing the resulting spectrum yields:

Line averaged spectrum shows:
- Few deuterons @ $V_{\text{cath}}$
- Spectrum consistent w/ spectra predicted by G.A. Emmert & J.F. Santarius
Previous work done by Thorson (1996) on radially profiling of a spherically gridded IEC device using a collimated proton detector

- Straight 10 cm collimator channel attached to moveable bellows assembly to obtain different lines of sight through the chamber
Previous Work Using Collimated Proton Detector

- Experiments conducted at 35 kV, 20 mA, 1.9 mTorr of Deuterium Pressure
- Cathode diameter: 10 cm

- Most fusion reactions (>90%) believed to occur outside of cathode region
**Time Of Flight (TOF) Diagnostic is an Advancement on the FIDO concept**

- TOF concept proposed by G. R. Piefer and D. R. Boris (2007) and implemented by D. R. Boris and D. C. Donovan (2008)
- 2 identical FIDO setups on opposite sides of HOMER
- Direct line of sight created through both arms and center of chamber
D-D fusion events can be detected using coincidence counting methods.

- Fast ions are accelerated radially towards the center of the electrodes.
- Fast particles most likely to collide with background neutrals.
• If the fast particle has sufficient energy, it fuses with the background neutral
D-D fusion creates 3.02 MeV proton and 1.01 MeV triton

Conservation of momentum requires both particles to move in exact opposite direction in center-of-mass frame

Proton moves approximately 3 times faster than triton, so for this setup, the proton always arrives at the detector first
Proper alignment is critical for capturing both fusion products of the same reaction.

- Distance between detectors: 2 meters
- Active Detection Area: 450 mm²
- Laser alignment used to ensure maximum exposure of detector face to chamber
Proper alignment is critical for capturing both fusion products of the same reaction

- Turnbuckle and steel cable used to support weight of arm and lead shielding
- Threaded rods used to properly position arm in 2D plane and align with arm on opposing side
Offset Angle Greatly Affects Detection Capacity

**After Alignment**
- <0.4 degree offset
- >80% Exposure

**Before Alignment**
- 1.5 to 2 degree offset
- ~20% Exposure
Si Charged Particle Detector

Pre-Amplifier

Energy Amplifier (~10 µs rise time)

Fast Filter Amplifier (~10 ns rise time)

Constant Fraction Discriminator

Delay Box

Time to Amplitude Converter (TAC)

Gate

Triton Arm Time Signal

Triton Arm Energy Signal

FIDO

TOF

Proton Signal

Energy

Time

Timing Electronics
Energy signal from detectors give velocity of fusion products.

Detector 1

Proton Arm
Energy Signal

Detector 2

Triton Arm
Energy Signal

\[ v_p = \sqrt{\frac{2E_p}{m_p}} \]

\[ v_T = \sqrt{\frac{2E_T}{m_T}} \]
TAC gives difference in arrival times, equal to difference in TOF of fusion products

\[ \Delta t = t_T - t_p \]

\[ t_p = \frac{r}{v_p} \]

\[ t_T = \frac{(L-r)}{v_T} \]

\[ r = \frac{L}{\frac{1}{v_T} + \frac{1}{v_P}} - \Delta t \]
Initial Results from Time Of Flight (TOF) Diagnostic

- Spatial resolution is roughly 2 cm
- Initial results have been achieved that indicate a high concentration of reactions inside the cathode
Initial results indicate at least 50% of fusion occurring within the cathode radius.
Conclusions for TOF

• Constructed and currently implementing a fusion product time of flight diagnostic capable of measuring the radial spatial profile of fusion reactions within the UW IEC device.
  – The TOF diagnostic has demonstrated the ability to generate spatial profiles of fusion reactions occurring within an IEC device
  – Original Thorson results indicated less than 10% of D-D fusion events occurring within cathode radius
  – Initial TOF results indicate that at least 50% of the D-D fusion reactions within the IEC occur within the cathode radius
Future Plans for TOF

• Implement electronics and software to capture simultaneous energy and timing signals for reactions to obtain 3D plot of:
  – Location of fusion event along radial line
  – Energy of fusion reactants at each location
  – Number of counts

• Use TOF diagnostic to study the change in energy and spatial profiles due to variations in:
  – Voltage
  – Current
  – Pressure
  – Grid Configurations