RESEARCH STATUS OF
IEC EXPERIMENTS
AT NASA MARSHALL

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NASA MSFC, PRC/TD40, HUNTSVILLE, AL

IVANA HRBUD, ERC, INC., NASA MSFC GROUP, HUNTSVILLE, AL
PRESENTATION OUTLINE

* IEC HISTORY AT PRC-NASA MSFC

* EXPERIMENTAL APPARATUS

* IEC PLASMA IMAGES

* DIAGNOSTICS

* RESULTS

* 3RD US-JAPANESE EXCHANGE/IEC WORKSHOP

IVANA HRBUD/MSFC-TD40
IEC HISTORY AT PRC

1997
- Preliminary studies and discussions with UIUC

1998
- SBIR-Phase I, NPL Associates & UIUC

1999
- SBIR-Phase II, NPL Associates, UIUC.
- Dr. Jon Nadler (UIUC) and Ms. Chantelle Hurst (Purdue University) join PRC through SFFP.
- UIUC loans IEC experiment to PRC for initial operation and design template for PRC’s IEC experimental program.
- Submitted CDDF proposal.
- Design and procurement of 2-foot vacuum chamber.
IEC HISTORY AT PRC

* 2000

- CDDF approved for IEC propulsion research.
- Design of PRC vacuum chamber, procurement of all major components and build-up of laboratory facility.
- Identified grid manufacturing techniques and conducted grid fabrication experiments.
- Design of pulse forming network for pulsed, high-power operation.
- Ms. Chantelle Hurst (Purdue University) joins PRC as Accompanying Faculty Student.
- PRC's IEC experiment generates plasma with Ar, He, and N₂.

* 2001

- Set-up of all major diagnostics and IEC plasma with H₂ (safety certification).
- Ms. Chantelle Hurst (Purdue University) joins as USRP.
- IEC plasma with Deuterium
2-foot, double-wall Spherical Vacuum Chamber
5-kW High Voltage Power Supply by Hipotronics

Plasma Diagnostics
- Neutron Detector (Ag Counter, He3)
- Photon Emission Spectroscopy
- Thomson Scattering (under development)
- X-Ray Detectors
- Microwave Interferometer (near future)

Laser Specifications
- Pulsed Nd-YAG Laser
- 1J/pulse, 10Hz

ICCD Gated Camera

Propellant Feed System
IEC SCHEMATICS

- Bottle Valve
- Line Valve
- S.O.V.
- Relief Valve
- Inlet Line
- Choke Orifice
- Inlet
- Wall
- Exhaust Line
- Valve Panel
- Chamber Valve
- Vacuum Chamber
- Gate Valve
- Turbo Pump
- Turbo Valve
- Roughing Valve
- Foreline
- Purge Inlet
- Diaphragm Pump

Gas Feed Inlet
- Cathode Grid
- To Vacuum Pump
- High Voltage Feedthrough
- Power Supply

IVANA HRBUD/MSFC-TD40
FUSION AT PRC

* IEC Operation:
  - Ar, He, N₂ (12-00)
  - Protium (06-01, 01-02)
  - Deuterium (08-01, 01-02)

* Mid August fused Deuterium and generated Neutrons for the first time with PRC's IEC experiment.

* Experiment generated a stable, sustainable, continuous and fusible plasma at a variety of power levels and propellant mass flow rates.
### IEC DEUTERIUM EXPERIMENTS

<table>
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<th>Experiment</th>
<th>$p$ (mT)</th>
<th>$V$ (kV)</th>
<th>$I$ (mA)</th>
<th>$P$ (mA/kV$^{3/2}$)</th>
<th>$D$ (cm)</th>
<th>$r_+/r_-$</th>
<th>$S$ ($10^6$ n/s)</th>
<th>$Q$ ($10^{-9}$)</th>
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$^\wedge$Pulsed Experiments

**Where is our data?**
Relative Electrode Size and Fusion

- Neutron Rate (MHz)
- D-D Fusion Q (ppb)

Anode to Cathode Radius Ratio

Ivana Hrbud/MSFC-TD40
Typical Experiment Configuration

- High Energy Laser
- Delivery Optics
- Vacuum Chamber
- Plasma
- Beam Dump
- Collection Optics
- Pulse Generator
- Low-Light Camera
- Spectrometer

IVANA HRBUD/MSFC-TD40
**DETECTOR OPTIONS**

**Diffraction Spectrometer and Camera**
- Spatial Information Available
- Many Wavelength Channels
- Spectral Flexibility

**Interference Filters and Photodetectors**
- Mechanically Simple
- Physically Robust
- Signal vs. Resolution Flexibility
**RESULTS**

*Balmer Lines - D2 Plasma*

 photons / pixel / sec

<table>
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<th>Wavelength (nm)</th>
<th>Photons / pixel / sec</th>
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<tr>
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<td>600</td>
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**Note:** Neutral Atomic Species

Upper State $n = 3$

- $n = 4$
  - $\text{H}_\delta$
  - $\text{H}_\gamma$
  - $\text{H}_\beta$

- $n = 5$

- $n = 6$

Visible Spectrum
RESULTS

* IEC Data Set (8-21-01/Deuterium)

- Pirani Gage mT
- Flow Readout mlm
- High Voltage kV
- Supply Current mA
- Neutron Count cpm
- Rad 50 mrh
- PNR4 Neutrons mrh

Time (minutes)

Units

IVANA HRBUÐ/MSFC-TD40
RESULTS

Paschen Curves for Hydrogen Isotopes in IEC

Voltage (kV) vs Pressure (mT)

- Deuterium
- Protium
RESULTS

* IEC Radiation Conditions vs. Cathode Voltage

- Current (mA)
- Pressure (mT)
- Ag counter (n/s)
- Rad 50 (mrh)
- PNR-4 (mrh)
Calculation of Measurable Number Densities vs. Temperature

Central Number Density and Temperature Limits from IEC Thomson Scattering

Signal Noise Ratio = 10 for 8 Minute Measurement (T = -30°C)

7.6 mT D2, 12 kV.