

# **HIGH POWER PERFORMANCE OF THE DIII-D GYROTRON SYSTEM**

**Presented by  
J. LOHR**

**in collaboration with R.W. Callis, W.P. Cary, Y.A. Gorelov,  
R.I. Pinsker, D. Ponce, and R. Prater**

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# HIGH POWER PERFORMANCE OF THE DIII-D GYROTRON SYSTEM

John Lohr

R.W. Callis, W.P. Cary, Y.A. Gorelov, R.I. Pinsky, Dan Ponce, R. Prater  
*General Atomics, San Diego CA*

The gyrotron installation on the DIII-D tokamak comprises four gyrotrons in the 1 MW class at 110 GHz. Using the maximum capability of the system, 2.0 sec pulse length and greater than 2.0 MW injected power, a comprehensive experimental program has been completed. The effect of localized current drive on the 3/2 and 2/1 neoclassical tearing modes was investigated. Transport studies were performed using modulation and perpendicular injection. Initial studies of  $j(r)$  control with off-axis ECCD leading to advanced tokamak operation were performed. Total injected energy of greater than 4.0 MJ per tokamak pulse has regularly been achieved with 97 MJ integrated injected energy on the best single day of operations. Reliability, defined in terms of achieved versus requested power/pulse length, has steadily improved during development of the system to greater than 90%, which compares favorably with the neutral beam systems. Measurements of the polarization of the injected rf beams verified the performance of the polarizer mirrors and an automatic calorimetry capability was developed. Detailed infrared measurements of diamond window performance were made. Progress on the addition of two more gyrotrons will be described



# DIII-D 110 GHz ECH SYSTEM

## OPERATING GYROTRONS

CPI: *Tin Man* 1.0 MW 5.0 sec

Gycom: *Katya* 0.75 MW 2.0 sec

*Boris* 0.75 MW 2.0 sec

*Natasha* 0.70 MW 2.0 sec

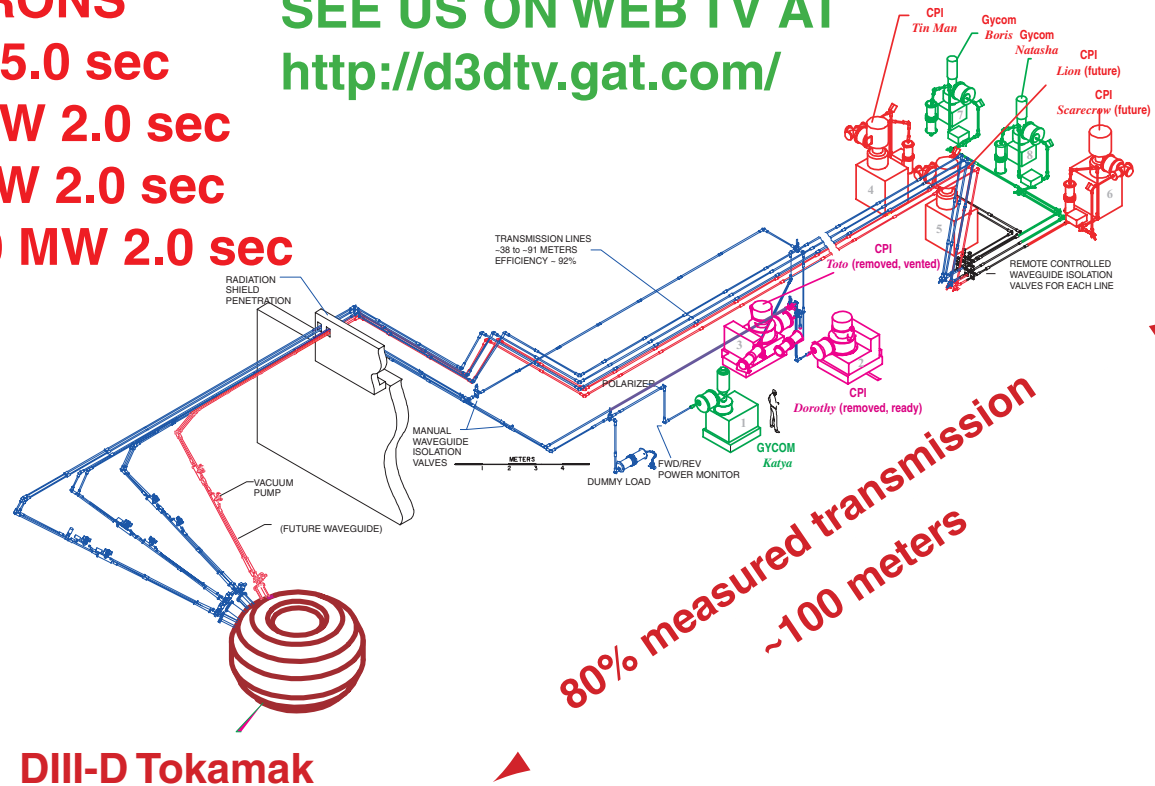
SEE US ON WEB TV AT  
<http://d3dtv.gat.com/>

## BEING INSTALLED

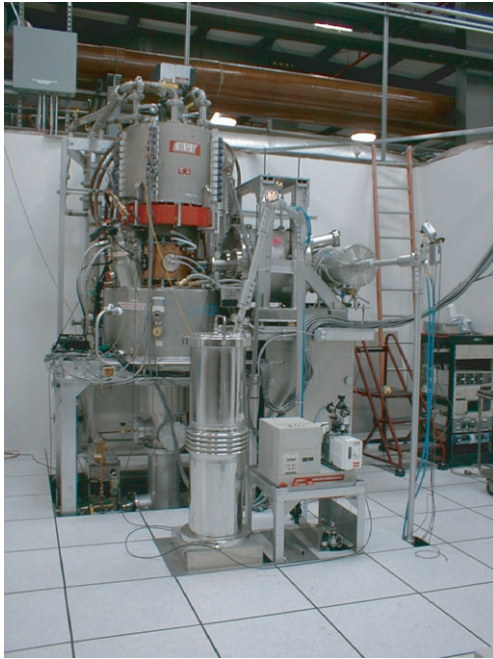
CPI: *Lion*

## IN TEST

CPI: *Scarecrow*



# DIII-D 110 GHz ECH SYSTEM



**CPI gyrotron *Tin Man* installed  
in the new ECH gyrotron vault**

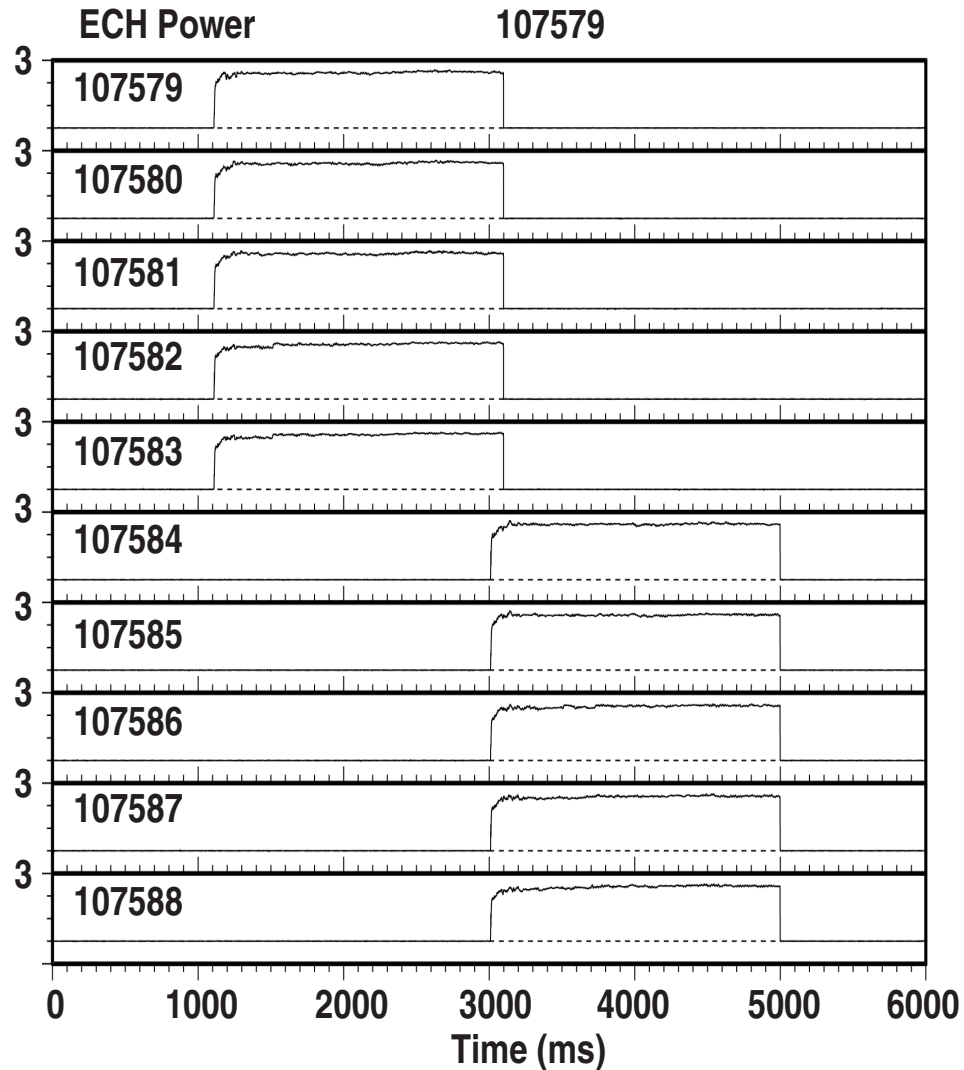


**Gycom gyrotron *Boris* installed  
in the new ECH gyrotron vault**

# DIII-D 110 GHz ECH SYSTEM

Reliability has become comparable to that of the neutral beam systems

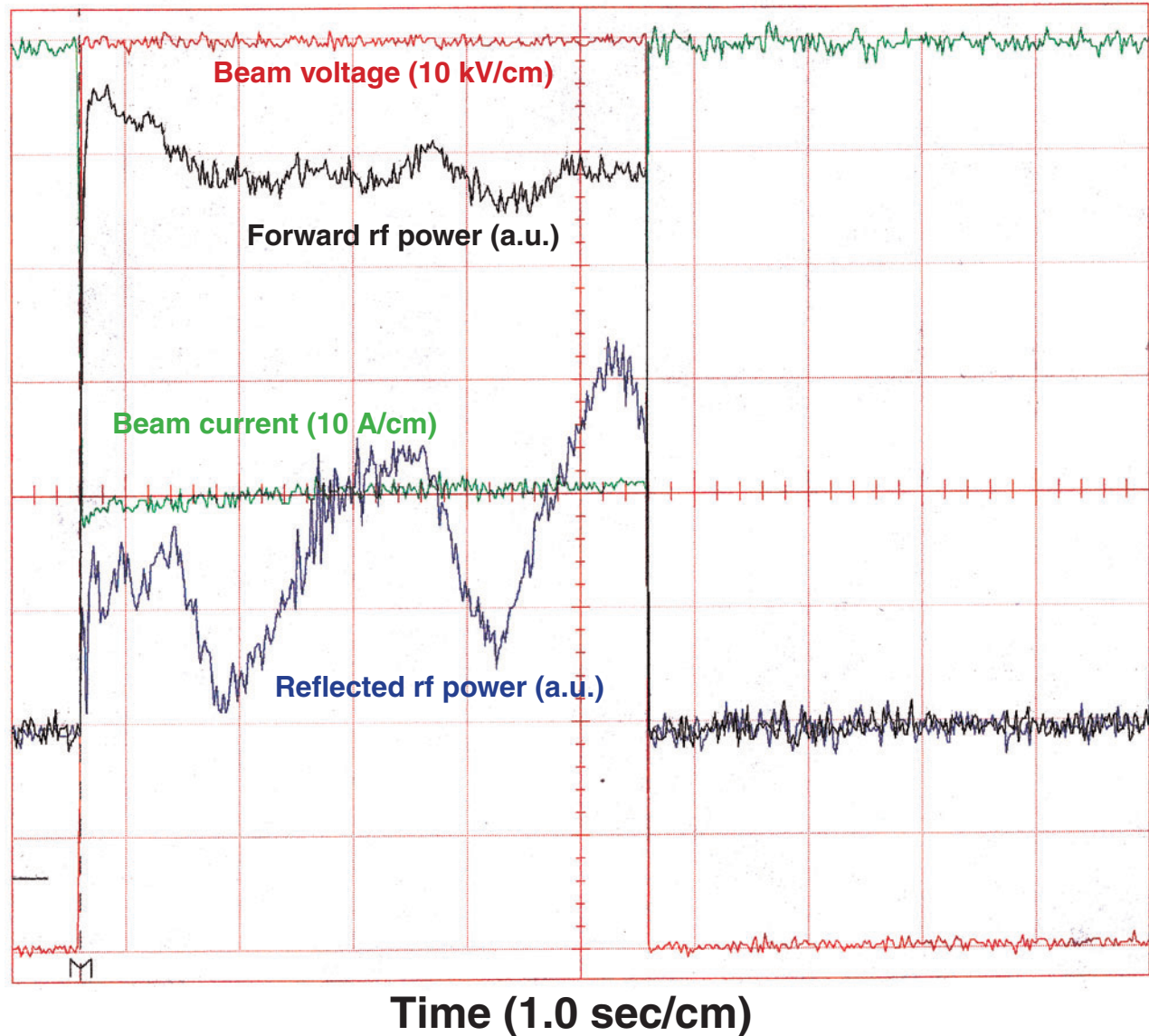
10 consecutive DIII-D shots



# DIII-D 110 GHz ECH SYSTEM

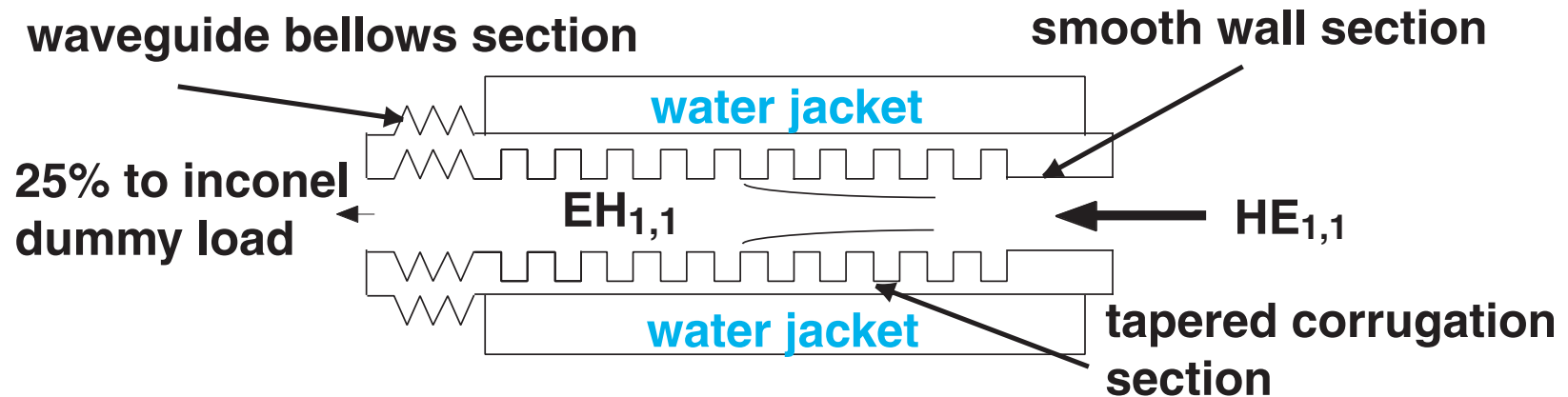
1.0 MW, 5.0 sec 17-Oct-2001

*Tin Man Gyrotron Operation*



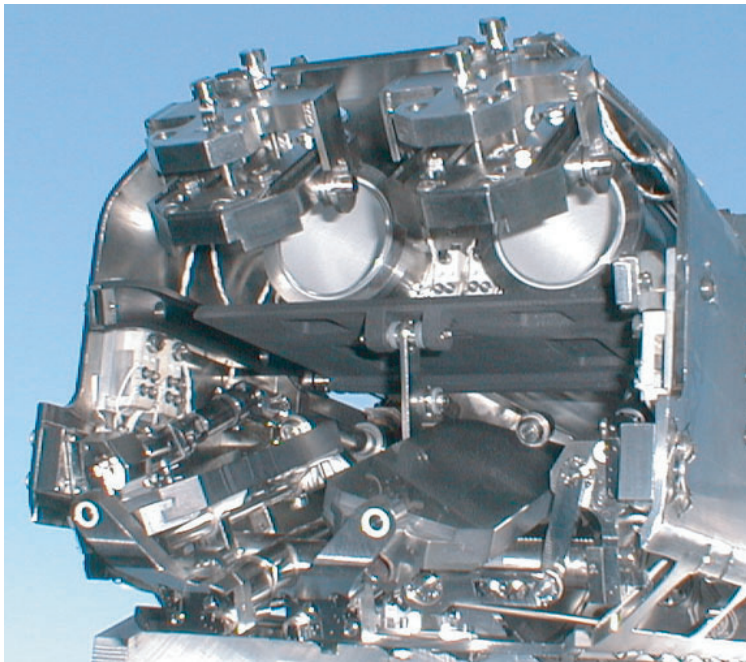
# NEW FEATURES

A new compact mode-conversion dummy load [John L. Doane, *Int. J. Infrared and Millimeter Waves*, 14, 363 (1993)] is now in service which absorbs about 75% of the incident  $HE_{1,1}$  mode and can be operated cw at 1.0 MW. This load is backed by a standard inconel dummy load which takes the remaining 25% of the power. The combination is extremely black with rapid calorimetry response.

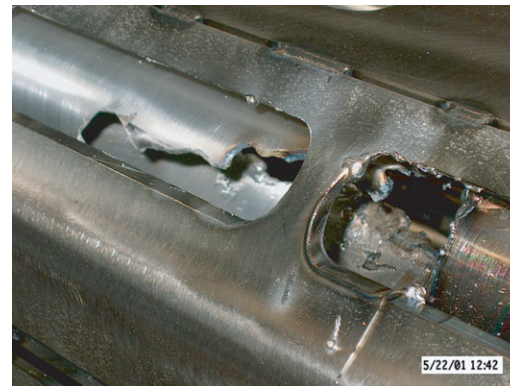
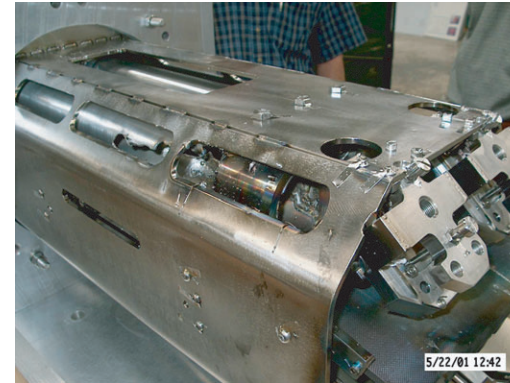


# NEW FEATURES

A new articulating launcher has been produced by PPPL, which can be swept both poloidally and toroidally. Two of these launchers, capable of handling four rf beams will be available for the 2002 campaign.



**PPPL articulating launcher  
First model in service 2001**



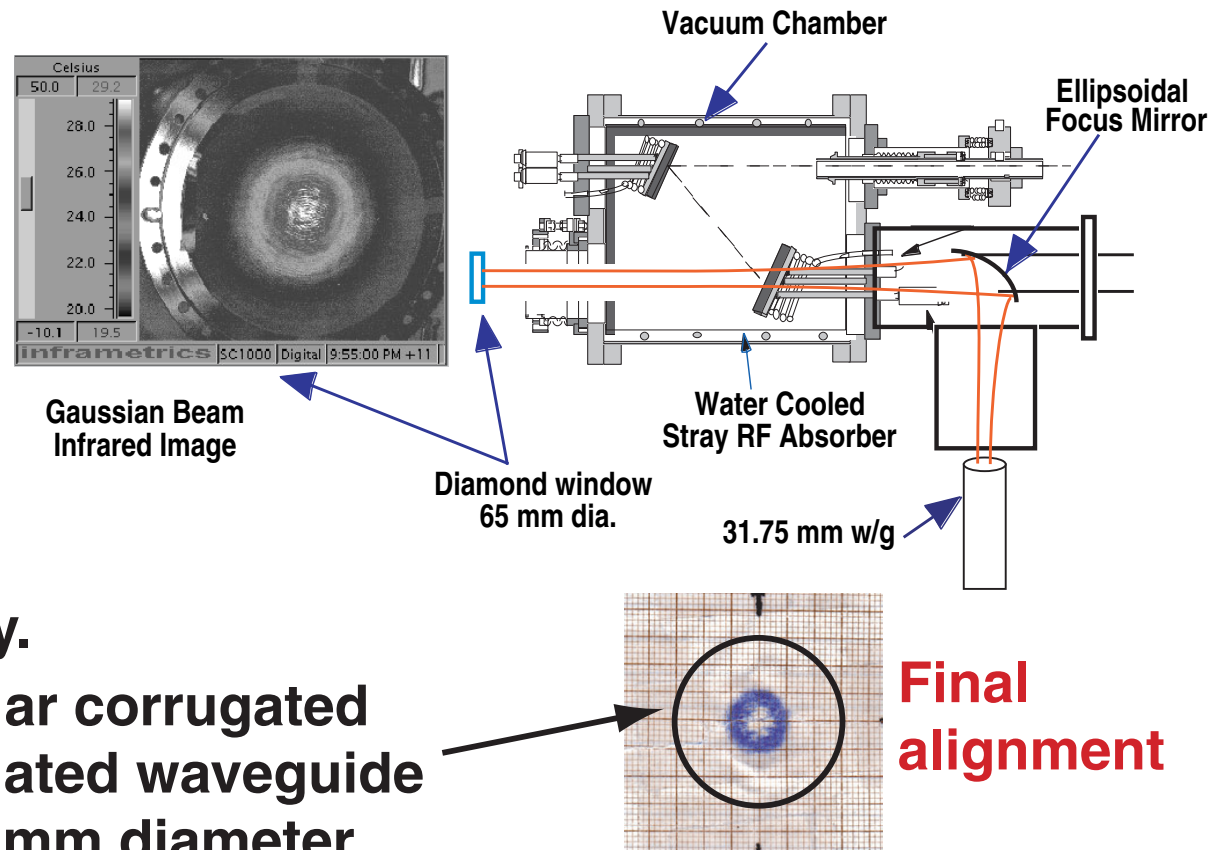
The launcher was damaged when the shutter failed to retract and the rf beam caused a breakdown. Both waveguides were melted.



# NEW FEATURES

The Gaussian output beam from the latest series of 1.0 MW gyrotrons couples to waveguide with <8% loss using the single mirror. This is about half the loss with the two mirror phase correcting system used previously.

## Waveguide coupling using one ellipsoidal mirror



Circular corrugated evacuated waveguide 31.75 mm diameter

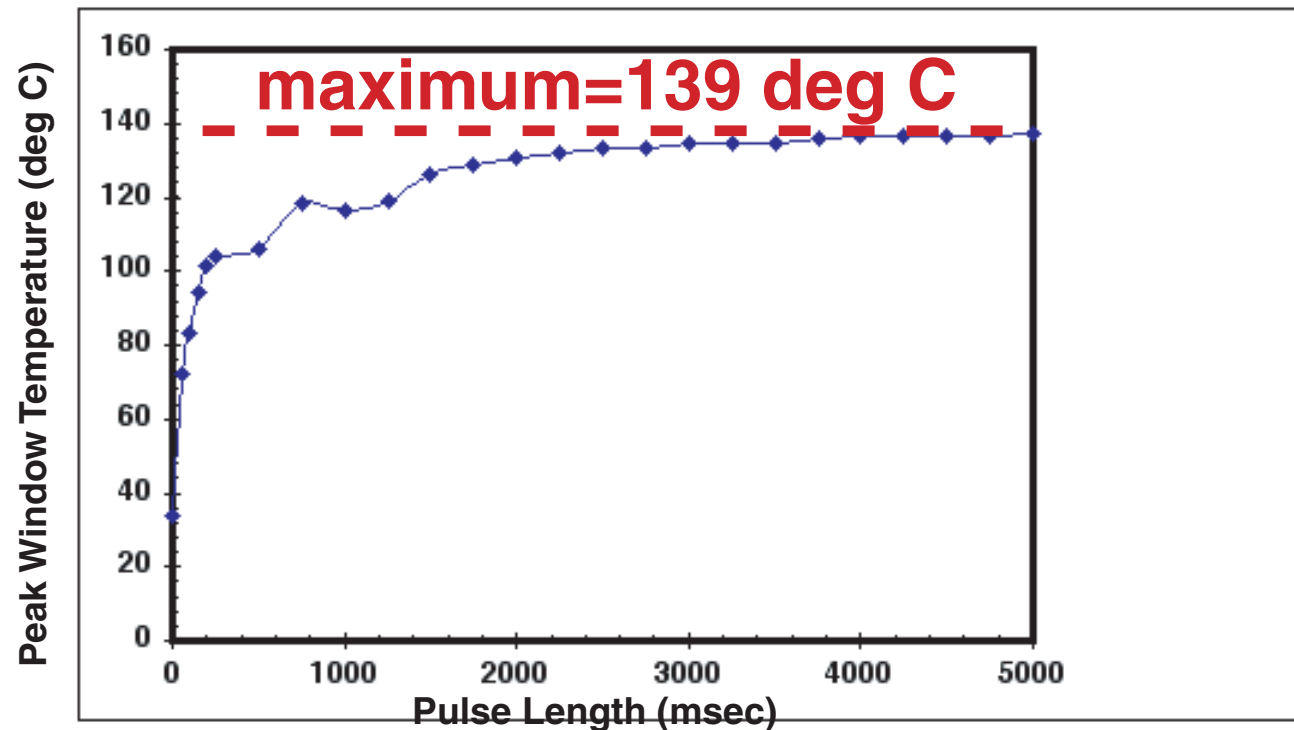
# DIAMOND DISKS FOR GYROTRON WINDOWS



**CVD diamond disks  
~\$100k (logo not included)**

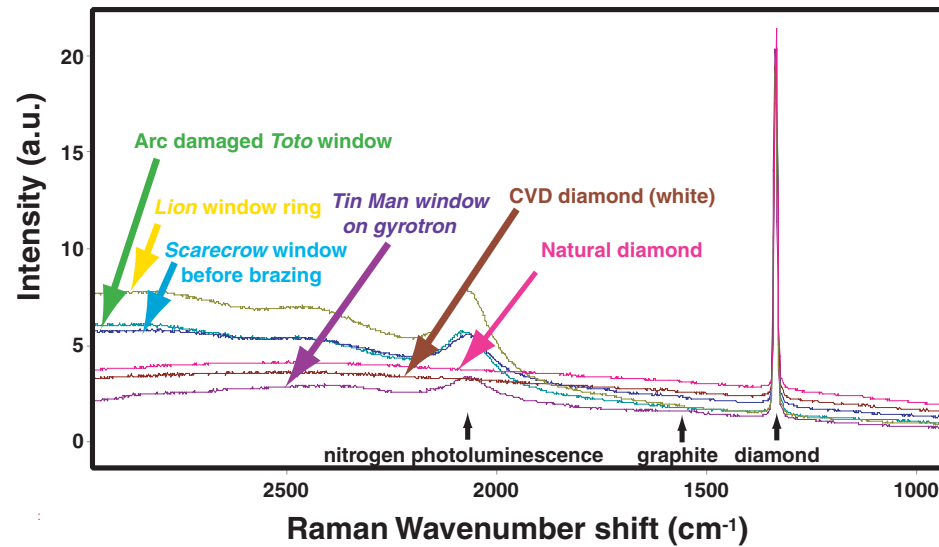
# DIAMOND DISKS FOR GYROTRON WINDOWS

IR measurement of the peak diamond window temperature for a 1.0 MW, 5.0 sec *Tin Man* pulse

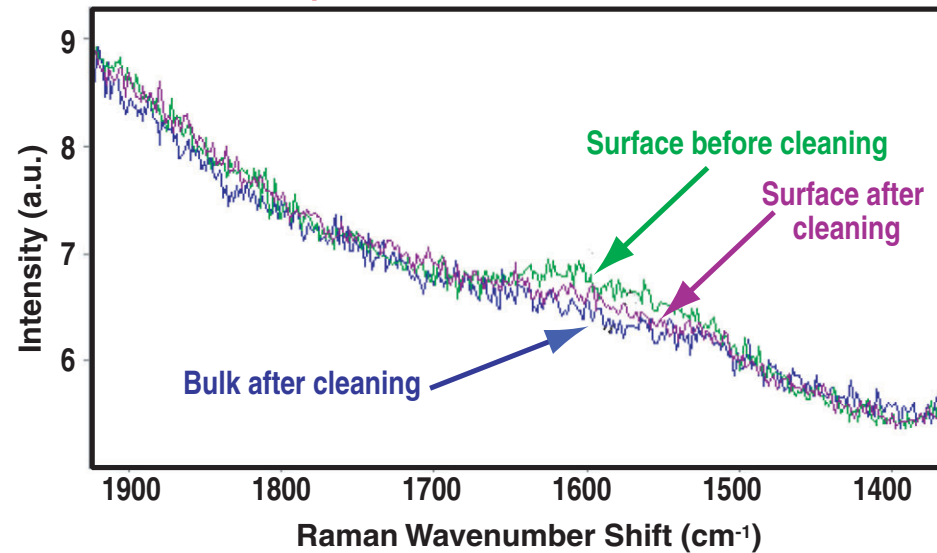


# DIAMOND DISKS FOR GYROTRON WINDOWS

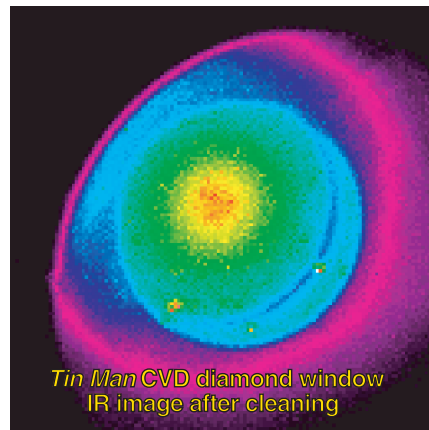
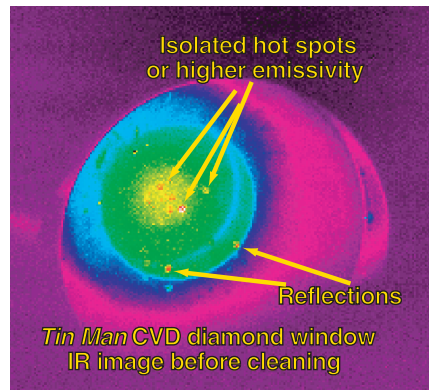
## Raman Spectra of CVD and Natural Diamond



## In Situ Raman Spectra of Tin Man Diamond Window Near Graphite Wavenumber Shift at ~1600 cm<sup>-1</sup>



# DIAMOND DISKS FOR GYROTRON WINDOWS



Several CVD diamond windows have failed due to contamination. Raman scattering measurements on the *Tin Man* window were made on the gyrotron, which verified the presence of graphite on the surface. "Hot spots" also were seen in the IR measurements of the window temperature during operation. The window was grit blasted with 3 micron alumina. This reduced the graphite and eliminated most of the "hot spots" from the IR measurement.

# **PARTIAL LIST OF ECH EXPERIMENTS DURING THE 2001 CAMPAIGN**

- **Suppression of 3/2 NTM and subsequent achievement of higher beta**  
An attempt to suppress the 2/1 NTM was not successful.
- **Studies of "heat pinch" and demonstration of negative central heat diffusion coefficient**
- **Direct verification of transport models**
- **Off-axis ECCD to create regime of advanced tokamak operation**
- **Effect of ECCD/ECH on creation of internal transport barriers**
- **Efficiency of ECCD leading to understanding of the effect of electron beta on the current drive process**
- **Efficiency of ECH**
- **Use of EC preheat to freeze profiles**

# SUMMARY

The CPI Tin Man gyrotron has generated 1.0 MW for 5.0 second pulse length.

The 2001 campaign had 4 gyrotrons with injected power >2.0 MW and good reliability.

The 2002 campaign will have two additional gyrotrons and the injected power will be >3.3 MW. Three of the gyrotrons will have pulse length capability of ~5.0 seconds.

The 2002 campaign will feature two ECH dual articulating launchers and one launcher with poloidal scan and fixed toroidal angle.

CVD diamond windows are now being used successfully on the new gyrotrons.

Raman scattering was used to diagnose the cleanliness of CVD diamond and cleaning of the *Tin Man* window was successful.

The waveguide transmission lines, dummy loads, polarizers, couplers, power monitors and other components are fully capable of handling 1.0 MW generated rf power for up to 5.0 second pulses and probably can be operated for substantially longer pulses.

Experiments on transport, NTM suppression and advanced tokamak operation have been performed.