

# **Future Plan of TPE-RX Experiment**



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## **IEA RFP Workshop**

**at Madison**

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# **Main Issues in TPE-RX Experiment**

## **Estimation of Confinement Property**

### **Improvement of Confinement**



#### **1. Measurement of Plasma Parameters**

**Profiles of  $T_e$ ,  $T_i$ ,  $n_e$ ,  $D_a$ , Impurities, etc.**

**Detailed analysis of  $\delta B$ . Edge plasma measurement.**

#### **2. Control and/or suppression of wall locked mode.**

#### **3. Reduction of $V_{loop}$ and realization of IHT mode.**

**Optimization of operation, control of Btw wave form**

#### **4. Reduction of $\delta B$ and improved confinement by the control of dynamo effect**

**Passive ; Using decay phase (??  $V_{loop} < 0$  as in ZETA, MST)**

**Active ; PPCD, Direct current drive by NBI (and/or RF)**

#### **5. Finally Increase of $I_p$ to 1MA**

**$I_p \sim 0.75MA$  will be realized within 3-4 years.**

**depending on suppression of wall locked mode**

# Near Term Plans 1

## Machine & operation



- 1. Plasma Rotation by magnetic field => unlocking & reducing dB**  
Rotating  $B_r$  ; Power supply is being installed, tried by summer.  
Rotating  $B_t$  ripple as in RFX ; Power supply is being prepared.  
Aiming the higher  $I_p$  (>500kA) operation.
- 2. Power up of Reversal Bank of  $B_t$  => high  $Q$  => IHT mode**
- 3. PPCD.**  
Independent power supply for single pulse is being considered.  
Power supply for multi-pulse PPCD is also being considered.
- 4. Reduction of Vloop**  
Impurities reduction => Ti gettering and/or boronization??  
Further investigation of EQ control by the DC vertical field  
Aided by ECH pre-ionization
- 5. Density control => Trial of high density operation.**  
Programmed gas flow and/or gas puff

# Near Term Plans 2

## Diagnostics 1

In addition to further ne, Te & Ti measurements.



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1. **Charge Exchange Recombination Spectroscopy with NBI**  
**plasma rotation & Ti profile**
2. **SX spectroscopy**  
**line intensity of Metals (Fe, Cr, Ni, etc.)**  
**continuous Te measurement (spectrum)**
3. **SBD tomography**
4. **Bolometer Array**  
**radiation loss profile**
5. **Visible, UV Spectroscopy**  
**impurity radiation profile in poloidal and toroidal directions**
6. **Edge probe**  
**Edge ne & Te, edge electric field, fluctuations**
7. **Interferometer; two colors (HeNe;3.39mm, CO2;10.6mm)**
8. **Magnetic fluctuations; mode analysis, EQ surface with dB**

# New Plasma Rotation Measurement System in TPE-RX

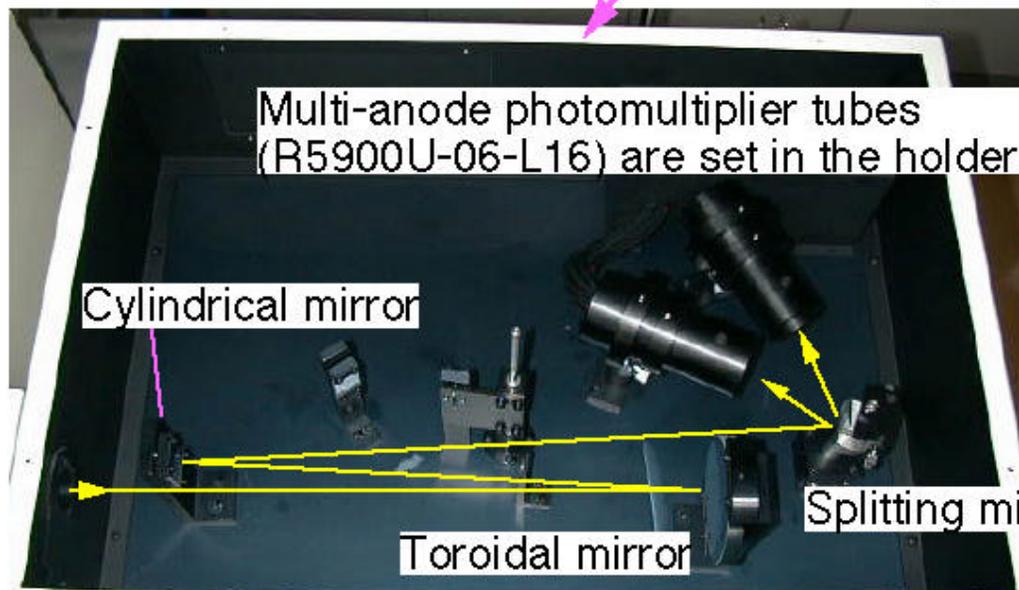


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1-m focal length spectrometer 2D magnifying optical system CR amplifier



Made by Bunkoh-keiki co.ltd



ADC

VAX

By adopting the cylindrical mirror, it is not necessary to adjust the focal position at each wavelength.

**This spectrometer is extended to the CHERS system using NBI.**

**H. Sakakita et al.; to be submitted to Rev. Sci. Instrm.**

# Near Term Plans 3

## Collaboration with RFX

Following plans are considered.



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1. Microwave reflectometer
2. Edge probes
3. SX detection (tomography & Te measurement)
4. Two Color Interferometer
5. Visible, UV, VUV, Grazing incidence, SX monochrometers
6. Bolometry ; multi channels.
7. 'Libero' experimentalists or data analysts  
who can flexibly work with us on various experimental subjects  
=> Depends on the major subjects
8. CAMAC ADC has already been borrowed. **Thanks a lot.**
9. Others

**Further collaboration with MST group is also expected.**

# Long Term Plans on TPE-RX

## Understanding transport and its improvement



- 1. Profile measurement of Temperature and Density**
- 2. Continuous Measurement of  $T_e$  (hopefully profile)**
- 3. Profile control and Control of dynamo**

**Main tool will be NBI**

**Central heating =>  $T_e$  &  $T_i$  profile control**

**Understand of transport with independent heating source.**

**Formation of Internal transport barrier aided with PPCD???**

**Momentum Drive & Poloidal Current Drive**

**Tangential ports are required => Modification of machine**

**NBI is quite expensive!! => Financial problem for Sufficient Pw.**

**Purchase of NBI will be started from the next fiscal year.**

**It will take for 3-4 years for installing complete system.**

# Poloidal Current Drive

## Possibility in TPE-RX



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### RF (frequency at $I_p=250\text{kA}$ )

**Fast Wave** ( $< \sim 10\text{MHz}$ ,  $\omega_{ci} \sim 1-2.5\text{MHz}$ )

Best for reactor, but difficult antenna design in TPE-RX

**Lower Hybrid Wave** ( $\sim 100\text{MHz}$ ,  $\omega_{ce} \sim 3-7.5\text{GHz}$ )

being tested in MST. Difficult in reactor.

Possibility of high power com-line antenna in TPE-RX??

**Whistler Wave** ( $\sim 2-3\text{GHz} < \omega_{ce}$ )

No realistic examination. Wave guide can be used. Accessibility?

**Electron Bernstein Wave** ( $\sim 6\text{GHz} \sim 2 \omega_{ce}$ )

No realistic examination. Wave guide can be used.

Is mode conversion from fast X-mode possible in RFP ???

**F-Theta pumping** ; requires large oscillation in  $I_p$  &  $B_{tw}$

**Bootstrap Current** ; requires large poloidal beta and small  $R/a$

**NBI** Direct current drive, Dynamo by pressure driven mode.

# Possibility of NBI Exp. In TPE-RX



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**It can be used in several purposes**

**Diagnostics, Heating, Profile control, Momentum & Current drive**

**Diagnostics => CHERS is OK. MSE is difficult in low B.**

**Key points of NBI design for heating and drive.**

**Low field & density => Orbit loss & Shine through**

**=> low energy beam,  $< \sim 25\text{keV}$**

**Small port Dia. (10cm) => Focused beam (Concave plate beam source)**

**Low driving efficiency => Large ion current ( $\sim 100\text{A}$ ) & Total input  $> \sim 1\text{MW}$**

**Central Heating**

**$n_{\text{NBI}} \sim 0.3\text{-}0.4\text{m}$  for  $n_e \sim 10^{19}/\text{m}^3$  => central heating is possible**

**$P_{\text{OH}} \sim 3\text{-}4\text{MW}$  (at  $I_p \sim 250\text{kA}$ ), Probably  $P_{\text{OH-center}} \sim 1\text{MW}$  at center**

**May show significant contribution to central heating when  $P_{\text{NBI}} \sim 1\text{MW}$ .**

**Poloidal current drive with  $\sim 2\text{MW}$  & appropriate angle**

**Poloidal current  $\sim 300 - 600\text{kA}$  may be driven.**

**15-30% of Total poloidal current  $\sim 2300\text{kA}$  at  $I_p \sim 250\text{kA}$**

**similar or larger value as that expected in PPCD of MST**

**Effect will be expected if  $P_{\text{NBI}} \sim 1\text{MW}$  is absorbed at  $I_p \sim 250\text{kA}$ .**



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# NBI Plan in TPE-RX

3 steps for the improved confinement by using NBI.

New NBI specifications ; ~25keV, 50 A, 30 ms X 2

**Heating profile control, Current drive, Momentum drive**

For Example, Estimation of Central Heating

$$DW_p/W_p \sim (P_{NBI}/P_{OH}) \{t_{NBI-loss} / (t_{NBI-loss} + t_{NBI-slow})\}$$

$P_{OH} \sim 3-4\text{MW}$  (in Total at  $I_p \sim 250\text{kA}$ )

=> maybe  $P_{OH-center} \sim 1\text{MW}$  near center

$P_{NBI} \sim 1\text{MW}$  comparable to  $P_{OH-center}$  at center

$t_{NBI-slow} \sim 40\text{ms}$  for electron,  $100\text{ms}$  for ion

$E_b = 20\text{keV}$ ,  $n_e \sim 10^{19}/\text{m}^3$ ,  $T_e \sim 700\text{eV}$

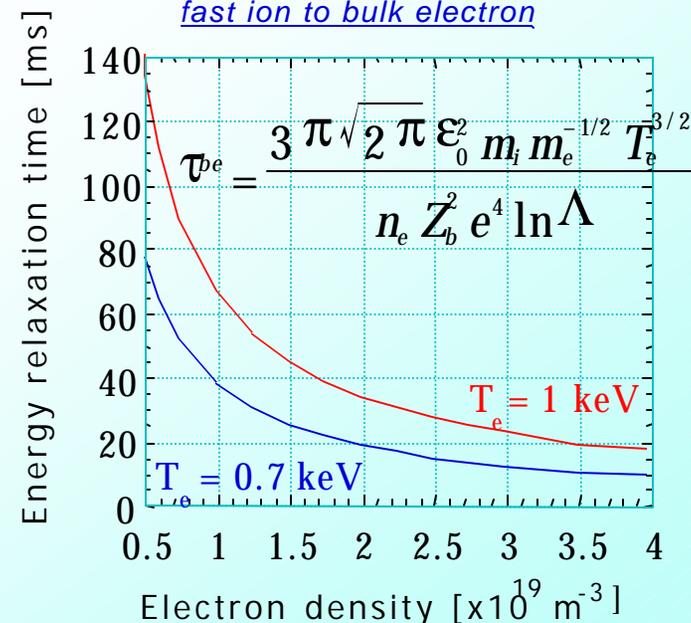
Key point ;  $t_{NBI-loss} > \sim 20\text{ms}$

=>  $DW_p/W_p > \sim 1/3$  near center

At least  $t_{NBI-loss} > \sim 10\text{ms}$  is needed.  $t_E??$

With PPCD or some other method!

*Energy exchange time from fast ion to bulk electron*



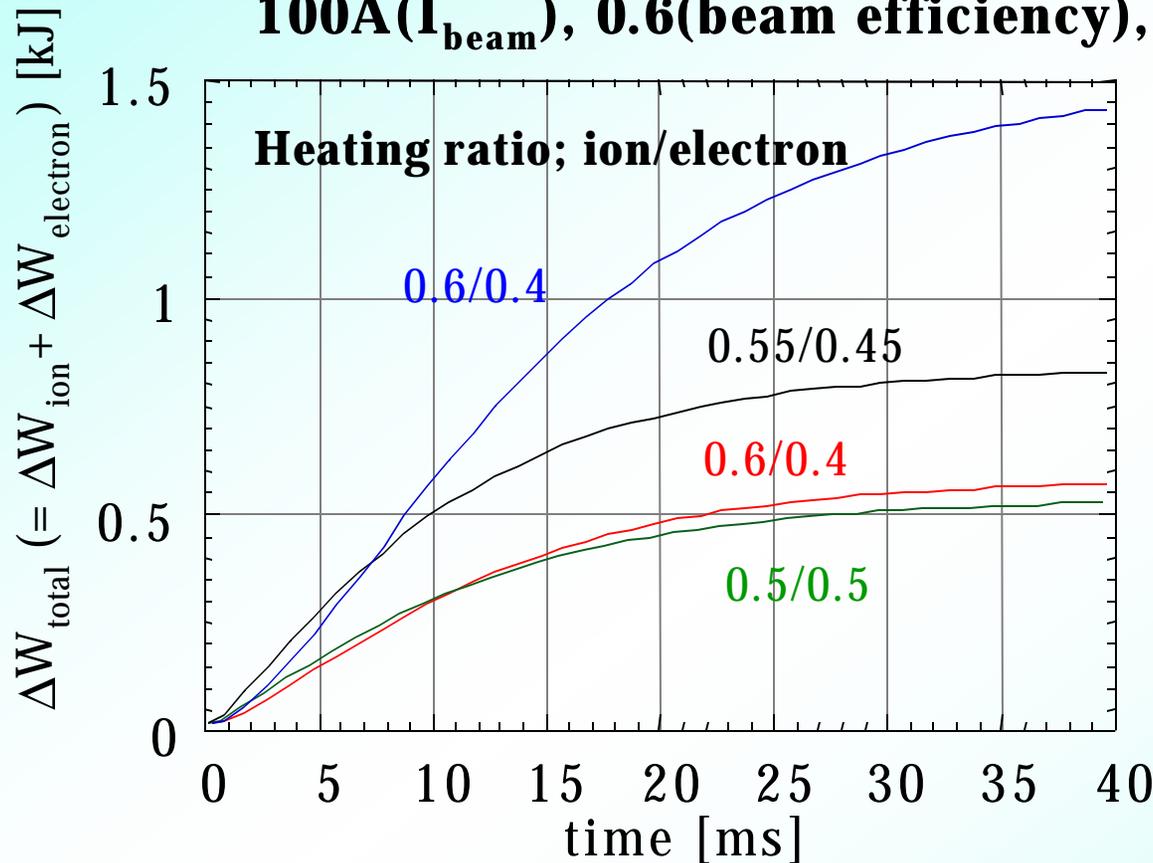
H. Sakakita et al.; Presented in APS meeting in Seattle (1999).

# Plasma energy obtained by NBI



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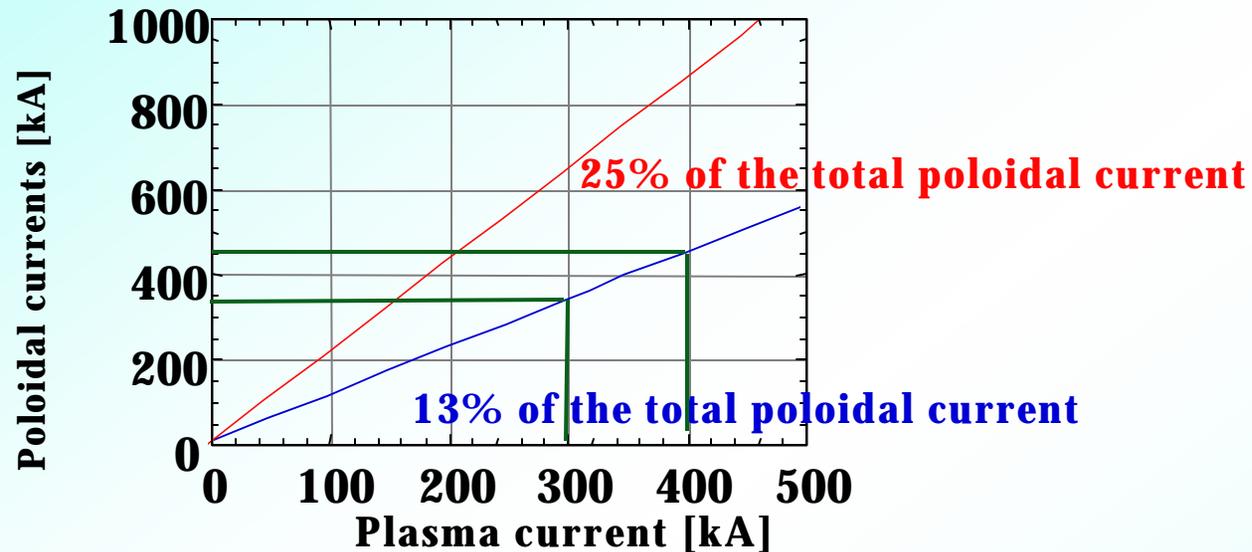
**100A ( $I_{\text{beam}}$ ), 0.6 (beam efficiency),  $t_{\text{beam loss}} \sim 10\text{ms}$**



**$W_{\text{plasma}}/3 \sim 1.5 \text{ kJ}$**   
**(at  $I_p = 250 \text{ kA}$ ,**  
 **$b_p \sim 0.1$ )**

- 20keV( $E_b$ ),  $1.5 \times 10^{19} \text{ m}^{-3}$ ( $n_e$ ), 0.7keV( $T_{e0}$ ), 5ms( $\tau_{Ei}$ ), 1ms( $\tau_{Ee}$ ), 70ms( $\tau_{\text{slow}}^{\text{ii}}$ ), 30ms( $\tau_{\text{slow}}^{\text{ie}}$ )
- 30keV( $E_b$ ),  $1.5 \times 10^{19} \text{ m}^{-3}$ ( $n_e$ ), 0.7keV( $T_{e0}$ ), 5ms( $\tau_{Ei}$ ), 1ms( $\tau_{Ee}$ ), 140ms( $\tau_{\text{slow}}^{\text{ii}}$ ), 30ms( $\tau_{\text{slow}}^{\text{ie}}$ )
- 20keV( $E_b$ ),  $2.5 \times 10^{19} \text{ m}^{-3}$ ( $n_e$ ), 0.5keV( $T_{ea/2}$ ), 5ms( $\tau_{Ei}$ ), 1ms( $\tau_{Ee}$ ), 50ms( $\tau_{\text{slow}}^{\text{ii}}$ ), 9.4ms( $\tau_{\text{slow}}^{\text{ie}}$ )
- 20keV( $E_b$ ),  $1.5 \times 10^{19} \text{ m}^{-3}$ ( $n_e$ ), 0.7keV( $T_{e0}$ ), 10ms( $\tau_{Ei}$ ), 5ms( $\tau_{Ee}$ ), 70ms( $\tau_{\text{slow}}^{\text{ii}}$ ), 30ms( $\tau_{\text{slow}}^{\text{ie}}$ )

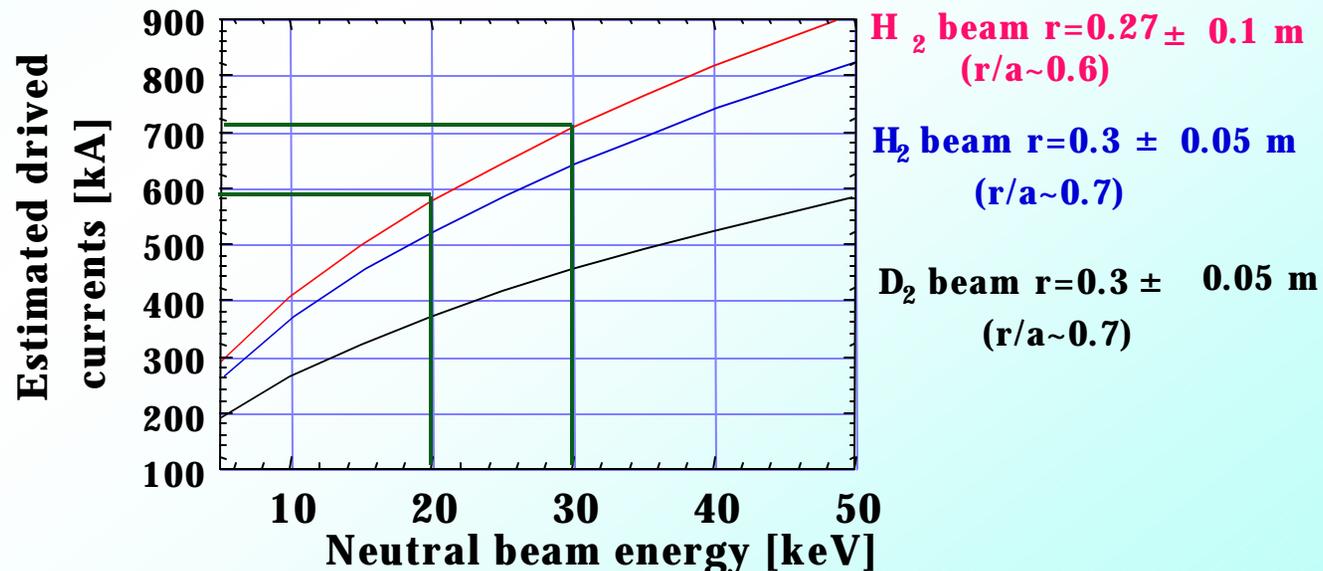
## Calculated poloidal current vs plasma current



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## Estimated driven current vs beam energy

100A( $I_b$ ), 0.5 (beam efficiency), 30ms( $t_{\text{duration}}$ ), 0.5 (parallel component), 3( $Z_{\text{eff}}$ )



# Test Module of Neutral Beam Injector Being prepared for TPE-2M



## Designed specifications

$P_{\text{NBI}} \sim 600\text{kW}$ , Energy 20keV, Current  $\sim 30\text{A}$ , Duration  $\sim 20\text{ms}$

Source area = 20cm x 10cm, Flat electrodes

Slightly focused by the displacement of electrode => Beam area 20cm x 8cm

Power supply ; capacitor bank (PFN)

## Present results

$P_{\text{NBI}} \sim 200\text{kW}$ , Energy 20keV, Current  $\sim 10\text{A}$ , Duration  $\sim 15\text{ms}$

Injection experiment on TPE-2M is being carried out.

## On TPE-RX.

This NBI will be installed in this year, hopefully by summer

Restriction of the port size => input power  $< \sim 100\text{kW}$  in full spec.

Sufficient for CHERS. It will start in this year.

Preliminary experiment

Penetration, Shine through, Impurity production, Operation

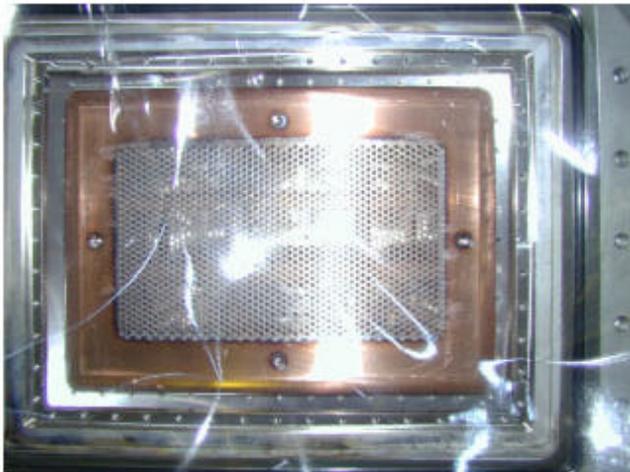
Profile Control ?? Dynamo by pressure driven mode??

# NBI Test Module

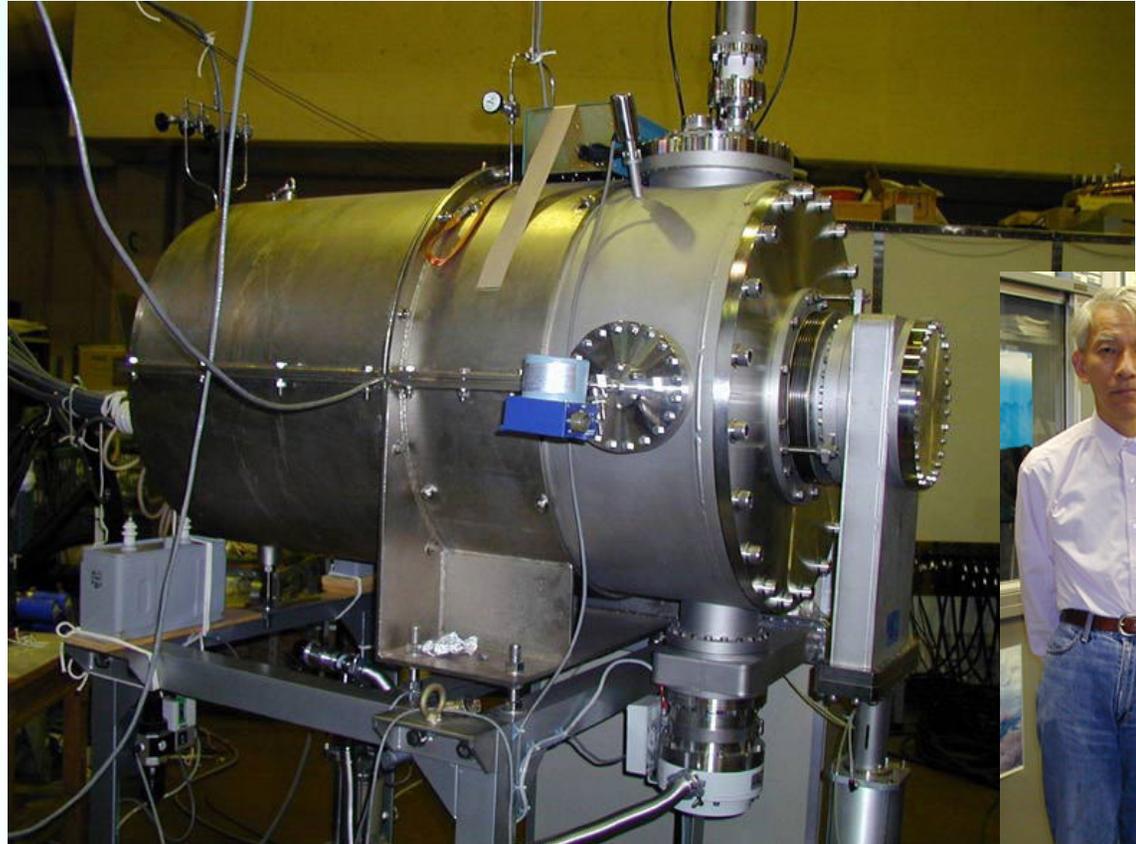
**600kW, 20kV, 30A, 10ms**



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**Beam Source**  
**The first electrode**  
**20 x12 cm**  
**Focused to 20 x 8cm**



# Finally



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**Our Laboratory will be restructured by April 2001.  
Will be privatized from National laboratory.**

**Possibly may not be so much different from JAERI.  
Name will be changed as well as the organization.**

**The name “Electrotechnical Laboratory” will be gone.  
In the meanwhile I anticipate there will not be a large  
change in our present research.**

**We will be able to continue the RFP experiment.  
But estimation may become more severe (practical??)  
Clear result (improved confinement) will be demanded.  
TPE-RX experiment needs stronger support and help  
from the worldwide RFP community than ever.**