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TRIP REPORT: US/JAPAN JOINT WORKSHOP ON RF HEATING AND CURRENT DRIVE

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TRIP REPORT

Stanley C. Luckhardt

U.S./Japan Workshop on RF Heating and Current Drive in Tokamaks

Trip Dates: December 1, 1981-December 10, 1981

Report Date: January 28, 1982

Traveler: Stanley C. Luckhardt, Research Scientist, Plasma Fusion Center, Massachusetts Institute of Technology, Cambridge Mass. 02139

Purpose: To give Paper at US/Japan Workshop on RF Heating and Current Drive and participate in discussions and information exchange to clarify our understanding of RF heating and current generation in plasmas, and its associated technology.

ABSTRACT

Methods of RF heating and current drive in tokamak plasmas are being studied intensively in the Japanese and American fusion programs. Scientific and technical progress has been very rapid in this field and new results are being generated on almost a monthly basis. This report summarizes the scientific and technical progress reported by the participants in the US/Japan work shop and the discussion of these results which followed the formal presentations. The experimental results of the various groups were generally in good agreement, but the theoretical interpretation of the results was unclear. A report on the site visits to JAERI, Kyoto University, and IPP Nagoya is also included.

TRIP REPORT

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INSTALLATIONS, ORGANIZATIONS, AND KEY PERSONNEL CONTACTED

JAERI Tokai Mura, Japan

December 2 (Wed), 1981

9:00	opening	K. Kagimoto (STA)	5 min.
		H. Ishikawa (JAERI)	5 min.
		R. A. Blanken (DOE)	5 min.
9: 5	Session A: Lower hybrid heating and current sustain		
	Lower hybrid heating and current drive experiment on PLT	W. Hooke (PPPL)	60 min.
	Lower hybrid heating and current drive on JFT-2	T. Yamamoto (JAERI)	30 min.
	Lower hybrid heating and current drive on JIPP-T-II	K. Ohkubo (IPP-Nagoya)	30 min.
11:20	discussion and information exchange		
12:30	lunch		
13:30	Session A. (continued)		
	Lower hybrid heating and current drive on WT-2	S. Tanaka (Dept. Physics, Kyoto)	30 min.
	Lower hybrid heating and current drive on the Versator Tokamak	S. Luckhardt (MIT)	60 min.
	Current drive experiment	S. Takamura (Dept. Elect., Nagoya)	15 min.
	Lower hybrid heating: Comments	A. Fukuyama (Dep. Elect. Okayama)	10 min.
		R. Itatani (Dep. Elect., Kyoto)	10 min
		K. Matsuura (IPP-Nagoya)	10 min.
15:45	discussion and information exchange		
16:45	leave for San-no-maru Hotel		
18:00	Welcome party at San-no-maru Hotel		

December 3 (Thurs), 1981

9:00	Session B: ECRH		
	ECRH experiment on JFT-2	K. Hoshino (JAERI)	30 min.
	ECRH experiments at 35 GHz on the Versator Tokamak	S. Luckhardt (MIT)	20 min.
	ECRH experiments on JIPP-T-II and NBT	H. Ikegami (IPP-Nagoya)	15 min.
	ECRH experiments on Heliotron	A. Ihyoshi (Heliotron Center, Kyoto)	15 min.
	ECRH Experiments on WT-2	Y. Terumichi (Dep. Physics, Kyoto)	20 min.
	Plans for 60 GHz ECH experiments on PDX and D III	R. A. Blanken (DOE)	30 min
11:20	Duscussion and Information exchange		
12:30	lunch		

13:30	Session C: ICRF	
	ICRF heating results on the PLT tokamak W. Hooke (PPPL)	60 min.
	ICRF heating results on JFT-2 H. Kimura(JAERI)	30 min.
	ICRF heating results on JIPP-T-II T. Watari(IPP-Nagoya)	30 min.
	comment for ICRF heating K. Miyamoto (Dep Physics, Tokyo)	15 min.
15:45	discussion and information exchange	
17:00	leave for San-no-maru Hotel	

December 4 (Fri), 1981

9:00	Session D: Theory	
	On confinement control by RF K. Itoh (JAERI)	30 min.
	Theory on Current Drive Y. Mizuno (IPP-Nagoya)	30 min.
	Theoretical results on RF heating and current drive S. Itoh (Hiroshima Univ)	30 min.
	Recent theoretical results in RF heating and current drive S. Liu(GA)	60 min.
12:00	lunch	
13:00	visit to the new site of JT-60 (by microbus)	
15:00	visit to the wooden mockup of JT-60 and JFT-2	
16:00	leave for San-no-maru hotel or free discussions	

December 5 (Sat), 1981

8:00 leave Mito for Kyoto
13:17 arrive at Kyoto, and leave for Heliotron Center
14:00 visit to Heliotron Center, (Uji campus of Kyoto Univ.)
17:00 leave for Kyoto (New Miyako Hotel)

December 6 (Sun), 1981

Holiday in Kyoto (New Miyako Hotel)

December 7(Mon), 1981

9:00 visit to Dep. Physics, Kyoto Univ. (WT-2)
14:05 leave Kyoto for Nagoya
14:53 arrive at Nagoya (Nagoya Castle Hotel)

December 8 (Tues), 1981

:00 visit to IPP-Nagoya
17:00 leave IPP-Nagoya for Nagoya Castle Hotel

December 9 (Wed), 1981

9:00 visit to IPP-Nagoya
13:55 leave Nagoya for Tokyo
15:56 arrive at Tokyo (Mitsui Urban Hotel at Ginza 8 near Shinbashi)

Participants of the workshop "RF heating/Current Sustain in Tokamaks"

The US delegation
Dr. R. A. Blanken (DOE), Dr. W. Hooke (PPPL), Dr. S. Liu(GA), Dr. S. Luckhardt (MIT).

The Japan Delegation
Dr. M. Tanaka(JAERI), Dr. Y. Tanaka (JAERI), Dr. T. Nagashima (JAERI), Dr. K. Itoh (JAERI), Dr. T. Yamamoto (JAERI), Dr. H. Kimural (JAERI), Dr. K. Hoshino (JAERI).

Dr. H. Ikegami (IPP-Nagoya)°, Dr. K. Matsuura(IPP-Nagoya)°, Dr. Y. Mizuno (IPP-Nagoya)°

Dr. S. Tanaka (Dep. Physics, Kyoto), Dr. Y. Terumichi (Dep. Physics, Kyoto)

Dr. Ihyoshi (Heliotron Center, Kyoto)

Dr. R. Itatani (Dep. Electronics, Kyoto)

Dr. S. Takamura (Dep. Electronics, Nagoya)

Dr. A. Fukuyama (Dep. Electronis, Okayama)

Dr. S. Itoh (Theory Center, Hiroshima)

Dr. K. Miyamoto (Dep. Physics, Tokyo)

°Keisei Hotel at Mito
others: San-no-maru Hotel at Mito

Observers
K. Inoue, A. Funahashi, K. Odajima, M. Matsumoto, S. Sengoku, M. Mori, T. Sugie, S. Yamamoto, N. Suzuki, T. Yamauchi, K. Maeno, Y. Miura, H. Ohtsuka, T. Imai, K. Uehara, T. Fujii, T. Takeda (Jaeri)

R. Sugihara, R. Kumazawa, M. Ichimura, T. Shoji, T. Aoki (IPP-Nagoya)

T. Maekawa (Dep. Physics, Kyoto), Y. Yasaka (Dep Electronics, Kyoto) M. Sato, T. Muto (Heliotron Center, Kyoto)

Y. Lojima, Y. Murayama, T. Kageyama, Y. Takahashi (NEC)

etc.

I. U.S. Japan Workshop - Summary of Results Presented

Lower-Hybrid Current Drive (LHCD)

Results of lower-hybrid current drive experiments on five tokamak installations were presented at this workshop. The Lower-Hybrid Current Drive (LHCD) experiments on the various tokamaks were generally agreed to be consistent with each other.

	Density Threshold	Typical Efficiency	Suppression of Runaway Flux to Limiter	Anti-Current Drive	Phase Dependence
JFT II	6×10^{12}	0.23kA/kW	yes	not observed	yes
JIPP II (Tokamak)	8×10^{12}	1kA/kW	yes	"	yes
(Stellerator)	1×10^{13}	0.25kA/kW	at low power	"	yes
VERSATOR II	6×10^{12}	1-2kA/kW	yes	"	yes
PLT	8×10^{12}	2kA/kW	yes	"	yes
WT-2	8×10^{12}	0.5-1kA/kW	yes	"	yes

All experiments reported an upper limit to the density at which current could be driven. This density limit to current drive is not predicted by the Fisch quasi-linear theory or the more sophisticated transport code studies of Englade et al. Suppression of runaway flux to the limiter is reported by all experiments during rf drive. Importantly, T. Yamamoto from the JFT-II group reported results from soft x-ray spectroscopy during LHCD. The JFT-II experiment shows an enhanced soft x-ray emission from the plasma center in the energy range 4-15kV and few (if any) higher energy X-rays. They conclude that there is little or no electron runaway production taking place during LHCD. A model electron velocity distribution fit to the soft x-ray data indicates $15A/cm^2$ of current driven in the center of the discharge by the rf.

LHCD Results (continued)

JAERI JFTII-Tokamak

For density in the range $1.5>\bar{n}>9\times10^{12}$ electron heating observed. Experiment was stopped March 1981. In the electron heating experiment ΔT_e = 250 eV was obtained with $P_{RF}\simeq$200kW and phasing $\Delta\phi$ = 180° with a four wave guide antenna. At lower density $\bar{n}_e\simeq 5\times 10^{12}$ current drive is observed with $\Delta\phi$=90°. The current drive antenna has its spectrum centered at N_{zo} = 6 and Δn_Z = 4. Other results include:

- SX spectroscopy shows flattened energy spectrum during rf pulse extending from 8kV to 18kV, no x-rays at high energy. Also, heavy impurity lines disappear due to reduction of runaway flux to limiter.
- The OH target plasma has a preformed tail extending out to 25-30kV. With impurity peaks of Fe, Cr, N Ti
- density buildup in RF pulse for $n_{eo} < 7\text{-}8\times10^{12}$
- density drop if $\bar{n}_e > 1\times 10^{13}$
- soft x-ray and Thomson scattering temperatures are in close agreement.
- shows cooling during current drive T_{eo}=900eV→500eV
- ΔV_L = 0.4V, $\Delta V_L/V_L$=40%
- $2\omega_{ce}$ radiation is reduced compared to the case without RF.
- current drive efficiency 0.17-0.23kA/kW.
- Claims agreement with quasi-linear theory of current drive if the antenna spectrum is down shifted, (but no sharp decrease of ΔI_{RF} with $\bar{n}$ predicted).
- intends to try (a) radial scan with SXR to get profile of I_{RF}; (b) high power current drive April 12, 600kW. (c) after construction of the new tokamak JFT 2M a 1.0GHz RF system will be installed with P=1-2 MW and a capability for long pulse operation for current drive.

LHCD RESULTS

JIPP-T II Tokamak-Stellarator

Current drive efficiency $\sim$1kA/kW tokamak

0.3kA/kW stellarator

- Spikes in V_L, $2\omega_{ce}$ bursts observed. Hard X-ray bursts observed during LHCD attributed to anomalous Doppler instability.
- 2-waveguide grill $\Delta\phi=\pi$
- density build up during RF and after rf off.
- effects are phase dependent, better efficiency at $\Delta\phi=\pi/2$.
- hard x-rays sometimes increase by x3-5 during high power LHCD.

These results are difficult to interpret due to the two waveguide design of the antenna. The power spectrum produced is not really appropriate for current drive.

WT-II Tokamak (Kyoto University)

This small tokamak installation has produced several interesting results. They have sustained the current with zero loop voltage. During current sustained operation $I_p \simeq 10$kA and is decaying for a period of 10msec. The ohmic heating transformer circuit; however, is in continuous operation making interpretation of the results difficult. The current sustained operation was observed in very low density discharges $\bar{n}_e \lesssim 3\times10^{12}cm^{-3}$. The current drive efficiency is 0.5-1.0kA/kW. The $2\omega_{ce}$ radiation increases by a factor of 10 during the RF pulse, and the soft x-ray range emission also increases. During the RF sustained phase the electron temperature falls to very low levels, the WT-II group estimates $T_e \simeq 30$eV.

The WT-II group interprets their results as due to the generation of a high energy electron beam by the RF power.

Ion Cyclotron Heating (ICRF)

Heating experiments were reported by the PLT group, and also by JAERI and IPP Nagoya. Similar heating efficiencies were reported for the three experiments.

JAERI JFT-II

Inside launcher, 2 ion hybrid heating mode.

- available 1MW, 18MHz
- into plasma up to 500kW

Antennas 2-1/4 turn loops, 35cm toroidal separation, zero phase difference. Only inside antennas are used now and the antenna design has all metallic construction with no ceramic break. The vacuum feed through has operated at power densities up to 7.0 kW/cm^2.

D-H experiments with 2-5% hydrogen minority at P=510kW, $\bar{n}=5\times10^{13}$ cm^{-3} gives ΔT_i=250-400eV with initial ion temperature of 350eV so the ion temperature approximately doubles in JFT-II.

Impurity radiation from high Z ions goes up by a big factor in low density shots but at high density the impurity radiation becomes less important. A low Z limiter is being prepared and will replace present molybdenum limiter.

JIPP-T II

Up to 400 kW of power has been injected. In the optimum case ΔT_i 320 eV with initial temperature of 250eV. So the central ion temperature has been doubled in this experiment at a density of $\bar{n}_e=2\times10^{13}$ and D/H plasma with 3% H minority. The JIPP-T-II group finds that heating of D/He^3 plasma has the same high efficiency as was observed in the PLT experiments. The heating efficiency at highest power levels is limited by an influx of heavy impurity atoms.

Electron-Cyclotron Heating (ECH)

ECH experiments were reported from the tokamak groups at JAERI, Nagoya, Kyoto University and MIT, and planned ECH experiments at GA and PPPL were described. The most detailed experiments were carried out on JFT-II.

(JAERI-GA) JFT-II

Power source was 28GHz, 200kW Varian gyrotron.
Three antenna configurations were used.

1. O-mode launch from low field side from 8 conical horn antennas.
2. X-mode launch from high field side with slotted waveguide antenna array. The launched wave vector was steerable in the horizontal plane over a range of ±45°.
3. TE_{02} launch with open ended circular guide from top of torus.

Heating results previously reported are:

1. 7.0eV/kW X-mode, 4.7eV/kW O-mode, 1.5eV/kW TE_{02}-mode at $\bar{n}_e \simeq 7\times10^{12} cm^{-3}$.
2. X-mode heating efficiency begins to decrease for $n_{eo} \gtrsim 1.2\text{-}1.3\times10^{13}$
3. O-mode heating efficiency begins to decrease for $n_{eo} \gtrsim 1.3\times10^{13}$
4. Best heating with X-mode launcher was obtained when waves were launched with nonzero $n_{\parallel} (\simeq 0.66)$.
5. Heating scales linearly with RF power.

Results of a preliminary EC current drive experiment were reported. The loop voltage drop during EC injection was measured as a function of X-mode injection angle ($n_{\parallel}$). For perpendicular and anticurrent drive injection angles ΔV_L of -0.13 to -0.20 Volts was obtained with $\bar{n}_e=5\times10^{12}$, B_{ϕ}=10kG. For injection angles appropriate for current drive ΔV_L was -0.2 to -0.29V. Electron heating was observed for all three injection angles, however the asymmetry in ΔV_L with injection angle was thought to be consistent with possible generation of 4kA of current. The JFT II team said that 10kA was expected on the basis of the theory of Eldgridge.

ECH RESULTS

JIPP-T-II (IPP NAGOYA)

Electron-cyclotron heating experiments were carried out on JIPP-T-II in the stellerator configuration. The radiation could be polarized and the antenna was located on the low field side of the torus. 35kW of injected power yielded ΔT_e=150eV with T_{eo}=450eV at $\bar{n}_e=5\times10^{12}$. The heating efficiency was found to decrease continually as the density was raised to 1×10^{13} and no heating was seen when $\bar{n}_e>1.3\times10^{13}$. A comparison of X and O-mode heating efficiency from the low field side launcher was made and the same efficiency was found for both polarizations, e.g. 2.2eV/(kW-10^{13}cm^{-3}).

WT II (Kyoto University)

Experiments carried out include EC heating of tokamak plasmas, EC assisted tokamak start-up, and plasma density build-up in a toroidal field without ohmic heating.

In heating experiments injection of 30kW of power at 35GHz (unpolarized) generated ΔT_{eo}=60eV, T_{eo}=160eV. Although the error limits on the Thomson scattering are comparable to ΔT_{eo}. A small density drop was also observed $\Delta n/n\sim10\%$.

In preionization experiments about a factor of 3 reduction in the initial loop voltage needed to start up the tokamak discharge was obtained. And in experiments without ohmic heating, a plasma with $n_e<1.4\times10^{13}$cm^{-3}, T_e=25eV was generated in a toroidal field of 12.5kG.

IPP Nagoya (Nagoya Bumpy Torus)

The NBT group reported two new results. They have succeeded in building up the density beyond the $\omega_o=\omega_{pe}$ limit. They report an increase in density ofΔ<nl> up to 2-2.5x10^{12}cm^{-2} above the $\omega_o=\omega_{pe}$ limit. They achieved this improvement by changing the location of the EC antenna from the mirror cell mid-plane and injecting toward a reflector in the mirror throat region thus the RF power propagates toward the $\omega_o = \omega_{ce}$ resonance from the high magnetic field side.

Experiments were also reported which identified the energy loss mechanism of the hot electron ring particles as mainly due to electron drag cooling of the high energy electrons on the background cold electron component. The decay rate of the ring was measured after shut off of the driving EC power pulse and compared to the classical dE/dt slowing calculations, and good agreement was found.

Theory

An important theoretical result was reported by Fukuyama, S. Itoh, and K. Itoh which may explain anomalous density changes which are observed in most ICRF, LHRF and ECH experiments. In a research report from the Institute for Fusion Theory at Hiroshima University (HIFI-51 Sept, 1981). These authors calculate the net forces on particles generated by wave absorption through wave particle interactions. In a talk at the RF workshop, K. Itoh discussed an application of the net force calculation to particle transport. They find that such net forces on particles arising from wave absorption lead to poloidal and radial drifts and hence in changes in the net particle containment. Either enhanced confinement or particle loss can occur.

SITE VISITS

A. JFT-II (JAERI)

Experimentation at JFT-II was mainly devoted to neutral beam injection (NBI) and ICRF over the preceeding several months. At the time of our visit NBI experiments were being carried out. The JFT-II lower hybrid antenna was removed from the machine in 3/81 to allow installation of an ICRF antenna.

The lower-hybrid experiments are planned to resume in 3/82 with an upgraded set of four klystrons; up to 600KW will be available for heating and current drive. A new solid titanium antenna has been built for these experiments. At present the antenna is installed on a vacuum tested stand. This stand is used to prepare the antenna and test its power handling capabilities. The antenna is baked at 450° C under vacuum on the test stand and is conditioned by repetitive pulsing of RF up to the full power available. The JAERI team also monitors the evolution of gas during baking and conditioning with a Mass-spectrometer (RGA). This test stand also has the capability of producing a plasma discharge in front of the grill; although, the experimenters feel there will not be enough time to try the plasma test before the antenna is installed on JFT-II in 3/82. The US delegation was very favorably impressed with this RF antenna test facility.

B. JT-60 (JAERI)

We also visited the construction site of the JT-60 tokamak. JT-60 is located within 15-20 minutes driving distance from the JFT-II laboratory. Building is underway at the JT-60 site. A combined office building, test staging area for the JT-60 lower-hybrid system has been completed. Also a building for housing the NBI power supplies has been completed. The JT-60 control building and experimental bay were under construction at the time of our visit.

The JT-60 lower-hybrid system will employ klystrons with 1.0MW output power at f_o = 2GHz. The completed system will operate at 30 MW with 10 MW delivered to the JT-60 plasma, 20 MW of power is lost in transmission. THE JT-60 antenna will be build of solid titanium and the atmosphere to vacuum windows are located outside the cyclotron resonance layer. The JAERI team expresses confidence that this antenna system will transmit up to 4.5 KW/cm^2 without breakdown or plasma formation in the waveguides. Two prototype klystrons have been developed for the JT-60 system one by NEC company and the other by Toshiba. Testing of the first prototype at the JT-60 site was scheduled to begin in 12/81. The klystron prototype with best characteristics will be chosen for the final JT-60 system.

C. Heliotron Center (Kyoto University)

We visited the Heliotron Center at Kyoto University for one half day. Professor K. Uo showed us the Heliotron E installation. This machine and associated diagnostic experiments was purchased as a complete system from Japanese industry, mainly from Hitachi. Shortly before we arrived one of the toroidal field coils on the machine burned out; the anticipated down time for Heliotron E was 2-3 months.

D. WT-II (Kyoto University)

This very active small university group is engaged in Lower-hybrid and ECH experiments. The experimental program is summarized in Section I of this report. The U.S. delegation was favorably impressed by the level and quality of work being done on this small tokamak.

E. IPP-NAGOYA

JIPP-T-II

The JIPP-T-II ICRF experiments were discussed with the JIPP-T-II RF team: Dr.'s Ohkubo, Iichimura, and Watari. During ICRF heating the ion temperature has increased from 200eV to 550eV as indicated by charge exchange measurements, with temperature rise and decay times of the order of $t_{ion} \sim 5$msec. They achieved the best heating results with virtual limiters beside the antenna. Without the limiter the charge exchange signal decayed rapidly after the RF pulse indicating poor confinement of the RF produced ion tail.

LHCD experiments were carried out using a two-waveguide C-shaped antenna, the results were discussed in Part I of this report. A frequency scan of electron cyclotron emission in the $2\omega_{ce}$ range was done during the LHCD experiment. The LH injection appeared to produce a steady-state cyclotron emission profile soon after the beginning of the RF pulse. This indicates that the RF generated electron tail is probably not evolving appreciably after it is initiated. The RF systems used on the JIPP-T-II tokamak-stellarator are described in Appendix II.

RFC-XX

The RFC-XX is an RF plugged cusp experiment at IPP Nagoya. The experiment consists of a double cusp with RF plugging of the line cusps. The field strength is 10kGauss in a straight section, 21 KGauss in the line cusp region and 39 KGauss at the point cusp. RF plugging is carried out with up to 1 MW of power at $\sim$13-30MHz. The DCLC mode is observed when RF is not applied to the line cusps; however, application of RF at 30MHz to the line cusps stabilizes the DCLC activity. Experiment indicate successful plugging of the line cusps by RF and increased particle confinement time; however the electron energy loss channel is still very important.

APPENDIX I

PARAMETERS OF SOME TOKAMAKS IN JAPAN

	PRESENT OPERATION	PLANNED UPGRADES
JFT-II (JAERI)	R_o = 90 cm a = 25cm B_T = 10-16 KG I_p = 20-170KA $\tau_{pulse} \sim$200msec T_{eo} = 500-1KV T_{io} = 850-500eV $\bar{n} \leqq 6x10^{13} cm^{-3}$	JFT-IIM R_o = 100cm (1982) a = 31cm $\tau_{pulse} \sim$1sec 4MW ICRF - 100-200KW at 40 MHz LHCD - 100-200 msec pulse (maybe 1sec) f_o = 1 GHz
JIPP-T-II (IPP NAGOYA)	a = 15cm (Tokamak) R_o = 91cm B_T = 26.4kG I_p = 80kA $\bar{n} = 2.5x10^{13} cm^{-3}$ T_{io} = 350eV T_{eo} = 700-800eV $\tau_{E-ion} \sim$6-7msec $\tau_{pulse} \sim$200msec.	JIPP-U-II a = 23cm (1983) R_o = 91cm I_p = 250KA 2 MW ICRF
WT-II (KYOTO UNIV)	R_o = 40 cm a = 9cm B_T = 13kG I_p = 30kA $\tau_{pulse} \sim$35msec $T_e \sim$200eV $\bar{n}_e \sim 2x10^{13} cm^{-3}$ $T_i \sim$60-80eV	

APPENDIX II

RF-SYSTEMS ON TOKAMAKS IN JAPAN

JFT-II (JAERI)

LHRF

750 MHz
P_{exp}=200KW
(600KW) 3/82
4 Klystrons Toshiba
4 waveguide antennas
3.3cm x 29cm
Ion Heating
1.5cm x 29cm
Current Drive

External Windows
Cyclotron resonance
under vacuum
Titanium Material

P/A ≃ .52KW/cm^2
Ion Heating
P/A ≃ 1.15KW/cm^2
Current Drive
in experiments reported.

ICRF

18-20 MHz
500-600 KW
(1 MW) available

2 antennas on
inside of torus
35cm toroidal
separation.

all metal construction
P/A=7.8kW/cm^2
at feed through

ECH

28GHz
150KW
(200KW)
(now unavailable)
Varian Gyrotron
Antennas;
High field side
X-mode steerable
slotted array

Low field side
O-mode
8 conical horn
antennas

Top TE_{02} circular
guide

JIPP-T-II (IPP-NAGOYA)

LHRF

800 MHz
160KW
(360 KW) available
2 Klystrons
40msec pulse

2 waveguide antenna
C-shaped waveguides
a = 5.9cm, b = 9cm

Internal windows
cyclotron resonance
pressurized
stainless material

P/A = 1.1KW/cm^2
in experiments reported.

ICRF

40KW
(2MW) 1983

3 all metal antennas
in place

ECH

35.5 GHz
40KW

32 Klystrons

Antenna:
X or O mode
polarization

On low field side,
circular waveguide
launcher.

WT-II (KYOTO UNIVERSITY)

LHRF	ICRF	ECH
915 MHz 20KW (100KW) available	-----	35.6 GHz 50KW Gyrotron made at Kyoto University T=8msec
Magnetron, ΔT=20msec		Antenna:
4 waveguide grill		TE_{01} circular mode waveguide
1.3cm x 18.5 cm		launch from top of torus on high field side
Internal Teflon sheet window		
Cyclotron resonance under vacuum		
P/A ≃ .21KW/cm^2		

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