3-24-83
WB

PPPL-1977

UC20-F

176
3-24-83

I 8451

PPPL-1977

Dr. 1270

Conf-820345-17

MASTER

LOWER HYBRID HEATING AND CURRENT DRIVE ON PLT

By

J.E. Stevens et al.

MARCH 1983

PLASMA
PHYSICS
LABORATORY

PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
UNDER CONTRACT DE-AC02-76-CDO-3673.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

J.E. Stevens, S. Bernabei, M. Bitter, F. Boody, N. Bowen, A. Cavallo,
T.K. Chu, S. Cohen, P. Colestock, S. Davis, C. Daughney, F. Dylla,
P. Efthimion, D. Herndon, E. Hinnov, W. Hooke, J. Hosea, J. Hovey,
H. Hsuan, D. Hwang, D. Ignat, F. Jobes, R. Kaite, J. Lawson, A. Martin,
E. Mazzucato, D. McNeill, S. Medley, E. Meservey, R. Motley, D. Mueller,
D. Ruzic, J. Schivell, F. Schnabl, R. Schwartz, J. Strachan, S. Suckewer,
S. von Goeler, and R. Wilson

Princeton University, Plasma Physics Laboratory

Princeton, New Jersey 08544 USA

ABSTRACT

800 MHz lower hybrid waves have been launched into PLT with a six waveguide coupler. Recent improvements have allowed power up to 400 kW to be launched with good coupling ($R \sim 10-25\%$). Experiments at low density ($\bar{n}_e < 7 \times 10^{12} \text{ cm}^{-3}$, i.e., $\omega/\omega_{LH} > 2$) have demonstrated current drive and plasma heating. Experiments at higher densities have produced hot-ion tails, but so far have shown inefficient body heating. To date, only a limited parameters space has been investigated at high power.

†Presented at the Third Joint Varenna-Grenoble International Symposium on Heating in Toroidal Plasmas, March 1982.

Grenoble, France

MASTER

REPRODUCTION OF THIS DOCUMENT IS UNLIMITED

Page 1

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

COUPLING

A schematic of PLT and the lower hybrid system is shown in Fig. 1. The waveguide dimensions are 3.5 cm x 22 cm. Low power measurements of reflection versus phase and reflection versus position show good agreement with grill theory.^{1,2} However, the power was initially limited to less than 35 kW/guide due to breakdown on the vacuum side. A new coupler was installed in September 1981 with the following changes:

1. The inside surfaces were coated with carbon to reduce secondary emission (multipactor).³
2. The ends of the waveguide partitions facing the plasma were rounded.
3. The primary limiters were moved from the coupler port to a location 80° toroidally away to reduce neutral gas pressure.
4. An additional gas puff valve, located far from the LH coupler, was used.

With these changes, the power per guide was increased to ~ 125 kW/guide (1.6 kW/cm²) (Fig. 2) without breakdown or arcing.

ION HEATING

Ion heating experiments have concentrated on the density range 1.0 to 3.0 x 10¹³ cm⁻³ in deuterium, i.e., $1.7 > \omega/\omega_{\text{LH}} > 1.0$. An enhancement of 2.5 MeV neutron emission is observed [$d(d,n)^3\text{He}$] at line average densities between

1 and $3 \times 10^{13} \text{ cm}^{-3}$ in deuterium. More than a two order of magnitude increase is seen at $\bar{n}_e = 1.6 \times 10^{13} \text{ cm}^{-3}$ (Fig. 3). The neutron signal decays with a time constant of approximately 18 ms. A hot ion tail is also observed with both the perpendicular and horizontally-scanning charge exchange analyzers at $\bar{n}_e > 10^{13} \text{ cm}^{-3}$. The most perpendicular component decays in < 5 ms, while the off perpendicular component has a much longer decay time. A tail temperature of ~ 12 keV is observed with the horizontally-scanning charge exchange analyzer along near perpendicular sightlines (Fig. 4), and by the spectral broadening of 3 MeV protons from the $d(d,p)t$ reaction.⁴ The location of the proton detector at the bottom of the PLT vacuum vessel allows counts only from reactions in the plasma.

Systematic explorations of ion heating as a function of density, magnetic field, gas mixture, waveguide phasing, discharge preparation, etc. are still in the early stages. Body heating observed to date has been inefficient. Figure 5 is a plot of $T_{i||}$ versus time measured by the horizontally-scanning charge exchange analyzer viewing the plasma tangentially. The line average density is $1.9 \times 10^{13} \text{ cm}^{-3}$ and the rf power is 390 kW. Because the rise and decay times are short, we infer that the radial location of the heating is probably not in the center of the plasma.

Parametric decay wave spectra are observed at densities $\bar{n}_e > 10^{13} \text{ cm}^{-3}$. The amplitude of the decay waves increases with increasing density, power, and decreasing magnetic field.

CURRENT DRIVE

Previous current drive experiments in tokamaks⁵⁻⁷ have been done with the discharge sustained at least partially by ohmic heating current or with the plasma current decaying. In these cases, it is difficult to show that it is not electric fields which drive the current because the resistance of the current carrying high energy electron tail can be much smaller than that of the electron body. Thus, a demonstration of rf current drive comes down to the question of whether electric fields are absent. In the present experiment, the ohmic heating drive is completely shut off, either by holding $\dot{I}_{OH} = 0$ or setting $I_{OH} = 0$, where I_{OH} is the primary current. The remaining voltage sources are due to $\dot{I}_{EF}$, $\dot{I}_p$, and $\dot{L}_i$, where I_{EF} is the vertical field current, I_p is the plasma current, and L_i is the plasma internal inductance per unit length. The total voltage for PLT is given by:

$$V_{OH} + V_{EF} + V_{IP} + V_{L_i} = 173 \dot{I}_{OH} + 87 \dot{I}_{EF} - \dot{I}_p [2.1 + 1.67 (L_i/2)] - I_p (0.83) (\dot{L}_i/2), \quad (1)$$

where:

$$I_{EF} = 0.0018 I_p (\ln 8R/a - 3/2 + \Lambda),^8 \quad (2)$$

V_{IP} is voltage induced by the changing plasma current and V_{L_i} is voltage induced by changing internal inductance. In Eqs. (1) and (2) I_p , I_{EF} , I_{OH} are

in MA, $\lambda = \beta_0 + l_1/2$, $R = 1.32$ m and $a = 0.4$ m. Equation (1) applies at the plasma center. The voltage at the vacuum vessel is given by the first three terms on the right side of Eq. (1), with the quantity inside the bracket in the third term replaced by 1.7. V_{OH} is the dominant term for typical parameters unless $\dot{I}_{OH} = 0$. When this is so, then current drive can be demonstrated when $\dot{I}_p > 0$ and $\dot{l}_1 > 0$. Although in this case, V_{EF} would aid the current, it is dominated by the voltages V_{Ip} and V_{l_1} which oppose the current. These simple considerations neglect profile effects, i.e., skin currents.

Figure 6 shows a case where the current must be driven by rf alone. With a waveguide phasing of $\Delta\phi = 90^\circ$, 100 kW of rf power is applied from 200 to 1000 ms. The plasma is formed by the OH primary current which stops increasing at $t = 100$ ms and reaches a constant value at $t \sim 200$ ms. The plasma current begins to decay immediately after the OH primary stops increasing until the rf is applied, at which time it is held flat and slightly increased. The loop voltage is negative during the initial part of the rf pulse, after which it stays near zero volts. The oscillations on the loop voltage signal are 60 cycle noise, and the ~ 50 ms delay for V_L to drop below 0 after rf is applied is partially due to a 40 Hz filter on the voltage. The density is initially brought up to $8 \times 10^{12} \text{ cm}^{-3}$ to help suppress runaways, after which it is kept at $2.5\text{--}3 \times 10^{12} \text{ cm}^{-3}$. The $\lambda = \beta_0 + l_1/2$ signal is derived from I_{EF} and I_p using Eq. (2). We note that a decreasing internal inductance can contribute to the current drive in some cases. The evolution of l_1 during the rf pulse depends on how the discharge is prepared before the rf is turned on. In particular, l_1 can decrease for long times in cases where the loop voltage is forced negative (by reversing $\dot{I}_{OH}$) before the rf is applied.

If more rf power is applied than is necessary to maintain $\dot{i}_p = 0$, then it is possible to increase the plasma current. Figure 7 shows the plasma current and loop voltage when 370 kW of rf is on from 300 to 500 ms. The plasma current is increasing by ~ 80 kA/sec at the end of the rf pulse, implying ~ 60 kW of power is going into increasing the poloidal field energy.

A fundamental aspect of the current drive process is its dependence on the phase of the rf. Figure 8 shows the theoretical wave number spectrum of the launched wave when the grill elements are phased $\Delta\phi = \sim 90^\circ$ apart. Approximately 88% of the power is launched in the $+z$ direction and the wave phase velocities correspond to velocities of 30-170 keV electrons. Changing the phase changes both the fraction of power launched in the electron flow direction (= directionality) and the energy of resonant electrons. For the PLT coupler these quantities behave approximately as:

$$\text{DIRECTIONALITY} \sim 0.4 \times \sin(-\Delta\phi) + 0.5$$

$$\text{RESONANT ENERGY} \sim 140/(\Delta\phi)^2 \text{ (radians) keV.}$$

Figure 9 shows the plasma current in response to 140 kW of power launched at several values of phase difference. The rf is applied from 250-750 ms. Current drive is progressively more efficient for phases with larger directionality and larger resonant energies. Negative phasings show little difference from the no rf case. The most efficient phases are -60° to -90° , while the least efficient phases are $+60^\circ$ to $+90^\circ$. When the magnetic fields and plasma current are reversed, then the phase of the waveguide must also be reversed to get the same effect. This shows that phase asymmetry is not purely geometrical, i.e., the result of backscatter from limiters or other obstructions.

In addition to phase, current drive also depends on density, plasma current, and rf power. Figure 10 is a plot of the power required to keep the plasma current flat ($\dot{I}_p = 0$) as a function of density. Power limitations in the rf circulators have prevented long pulse operation above 300 kW. The data show approximately the following figure of merit for $\bar{n}_e < 5 \times 10^{12} \text{ cm}^{-3}$:

$$\frac{\bar{n}_e I_p}{P_{RF}} \sim 0.6 \times 10^{13} \frac{\text{A}}{\text{W cm}^3} \quad (3)$$

An unexplained feature of the experiment is how the current can be maintained with a wave phase velocity much greater than the thermal velocity of the plasma. Theoretically,⁹ $\omega/k_{\parallel} v_e \sim 4$ is required for a reasonable amount of driven current at good efficiency, where ω is the wave frequency, $k_{\parallel}$ is the shortest parallel wavelength in the rf spectrum, and $v_e = \sqrt{T_e/m_e}$. Typical experimental values are $\omega/k_{\parallel} v_e \sim 6$ at the coupler. However, given that current is driven by the rf, an estimate of the power necessary to maintain fast electrons against slowing down can still be obtained from theory. Combining Eqs. (4) and (5) from Ref. 9, along with a correction term from Ref. 10, the following theoretical figure of merit is obtained for PLT:

$$\frac{\bar{n}_e I_p}{P_{RF}} \sim \frac{2.6 (n_{I2}^{-2} - n_{I1}^{-2}) \times 10^{13}}{\ln(n_{I1}/n_{I2})} \sim 1.2 \times 10^{13} \frac{\text{A}}{\text{W cm}^3} \quad (4)$$

Equation (4) takes $n_{||1} = 3.0$ and $n_{||2} = 1.5$ from Fig. 8. It is assumed that $n_e(0) = 1.5 n_e$, $Z_{eff} = 5$, and that 80% of the rf power is launched in the useful range of phase velocities. Equation (4) also includes the assumptions discussed in Refs. 9 and 10. By these crude estimates, the right side of Eqs. (3) and (4) show an experimental figure of merit comparable to that based on classical slowing down of electrons.

Direct evidence for the production of fast electrons has been obtained from electron cyclotron emission and from X rays. For densities $\bar{n} < 10^{13} \text{ cm}^{-3}$, the emission for $\omega = \Omega_{ce}$ and $\omega \approx 2 \Omega_{ce}$ is not blackbody radiation and the emission from superthermal particles with an intensity greater than the blackbody level is observed in PLT. When the rf is applied at these low densities during current drive experiments, there is an enhancement in this already high intensity emission. This enhancement correlates with the current maintenance by LH waves. Figure 1† is the time evolution of ordinary (O) mode emission near $\omega = \Omega_{ce}$ for four frequencies whose blackbody cyclotron resonant layers correspond to the radial positions shown and the extraordinary (X) mode emission near $\omega = 2 \Omega_{ce}$ at one frequency corresponding to the same blackbody cyclotron resonant layer as one of the four O-mode cases. The plasma center is at 130 cm and the edge is at 170 cm. Radiation corresponding to $\omega = \Omega_{ce}$ well outside the plasma ($R = 191 \text{ cm}$) shows that the frequency is Doppler shifted enough to imply that there are some electrons with energy at least 10-30 keV. O-mode radiation is sensitive to parallel electron velocities while the X-mode is sensitive to perpendicular velocities.¹¹ The fact that the O-mode emission jumps quickly after the rf is turned on while the X-mode emission rises slowly suggests that the rf quickly produces a parallel electron tail which then gradually pitch angle scatters.

The spectrum of hard X rays has been measured (< 500 keV) with a NaI detector viewing vertically through the center of the plasma column. Figure 12a is a plot of X-ray intensity as a function of energy for discharges with and without rf with line average density of $\bar{n}_e \sim 3 \times 10^{12} \text{ cm}^{-3}$. A Maxwellian, parallel-directed, electron distribution with temperature ~ 150 keV fits the x-ray distribution during the rf, although the fit is by no means unique. This is consistent with the launched spectrum from Fig. 8. The inset shows the time evolution of plasma X rays (bottom scope trace) as well as X rays (> 400 keV) emitted from the limiter (top scope trace, scale inverted). The rf power is 80 kW and is on from 300-700 ms. The x-ray emission from the plasma reaches a steady state approximately 50 ms after the rf turns on. The plasma X-ray intensity is increased by an order of magnitude by the rf while limiter X-ray emission is reduced.

At a higher density, $\bar{n}_e \sim 6 \times 10^{12} \text{ cm}^{-3}$, the intensity of X rays is much reduced for the no-rf case (Fig. 12b) but during the rf pulse the X-ray spectrum is almost identical to that of the low density (Fig. 12a) case. This suggests that the existence of fast electrons, per se, is not a necessary condition for current drive. X-ray emission from the limiters is less in the no-rf case, and is again reduced at the onset of the rf. Presumably the reduction in hard X-ray intensity is related to the reduction in loop voltage accompanying the rf current drive, either because runaway electrons stop gaining energy and drifting outward into the limiter or because they are no longer being formed.

Measurements of X-ray spectra with a silicon detector¹² in the energy range 1-30 keV also show the formation of a tail, which breaks with the body distribution at ~ 10 keV. Horizontal scans show that X-ray emission from the tail (~ 20 keV) is confined to the inner 15 cm of the discharge.

At densities above $\bar{n}_e \sim 7 \times 10^{12} \text{ cm}^{-3}$, current drive can no longer be sustained with the available power. At a density of $\bar{n}_e = 8 \times 10^{12} \text{ cm}^{-3}$, an energetic electron tail is still produced by the rf. The intensity of X-ray emission below 300 keV is less than what is seen in typical current drive cases. The electron body energy measured by Thomson scattering also decreases during the rf. The reason for the decreased tail and body heating at higher density is still under investigation.

ELECTRON HEATING

Besides driving the plasma current, the rf must also heat the plasma in cases where $\dot{I}_{OH} = 0$ and $\dot{I}_p, \dot{I}_1 = 0$. Figure 13a shows the energy content of the electron body measured by TV Thomson scattering during current drive, for a line average density of $5.7 \times 10^{12} \text{ cm}^{-3}$. Figure 13b shows the power input to the plasma as a function of time. Power from the OH primary is turned off after 100 ms, but power from the poloidal field continues to maintain the plasma. At 350 ms, 270 kW of rf power is applied and the inductive power input decreases to $\sim 10 \text{ kW}$. During the rf, the electron body energy content decreases from 1.8 to 1.3 kJ. However, this does not include energy in the electron tail, which exceeds the body energy if one assumes that fast electrons ($> 10 \text{ keV}$) carry all of the plasma current ($I_p = 220 \text{ kA}$). The peak electron temperature during the rf pulse is approximately 900 eV. The peak ion temperature measured by charge exchange is approximately 350 eV before, during, and after the rf pulse. From these data, the energy flow pattern can be concluded to be:

At densities below 10^{13} cm^{-3} , the three plasma components listed above are weakly coupled.

SUMMARY OF RESULTS

Some general observations can be made:

- (1) **Coupling:** The technical aspects of launching high power density lower hybrid waves look favorable. The fate of the wave after it leaves the coupler needs further investigation in all density regimes.
- (2) **Ion Heating:** A fast ion tail is formed, but body heating is inefficient to date.
- (3) **Current Drive and Electron Heating:** RF driven current can be maintained at low densities ($\bar{n}_e < 7 \times 10^{12} \text{ cm}^{-3}$; $\omega/\omega_{LH} > 2$) apparently not aided by the inductive sources $\dot{I}_{OH}$, $\dot{I}_{SF}$, $\dot{I}_p$, and $\dot{I}_1$. The magnitude of driven current depends on waveguide phasing, rf power, and plasma density. Current drive and electron heating are linked; the rf power must completely determine the plasma steady state. Thus, the efficiency shown in Fig. 10 [and Eq. (3)] may not be indicative of the

efficiency of current drive alone. Only a small range of parameters has been explored; in particular, the rf spectrum suggested by theory ($\omega/k_{\parallel}(\max)v_e \sim 4$) has yet to be tried.

ACKNOWLEDGMENTS

We thank the rf technical staff, the PLT support staff, and the PLT technical staff for their numerous contributions to this project. This work supported by the U.S. Department of Energy Contract DE-AC02-76-CHO-3073.

REFERENCES

- ¹ M. Brambilla, Nucl. Fusion 16, 47 (1976).
- ² J. Stevens et al., Bull. Am. Phys. Soc. 26, 974 (1981).
- ³ D. Ruzic et al., Princeton University, Plasma Physics Laboratory Report PPPL-1874 (1982).
- ⁴ R. Chrien, Ph.D. Thesis, Princeton University, 1981 .
- ⁵ T. Yamamoto et al., Phys. Rev. Lett. 45, 716 (1980).
- ⁶ M. Nakamura et al., Phys. Rev. Lett. 47, 1902 (1981).
- ⁷ S. Luckhardt et al., Phys. Rev. Lett. 48, 152 (1982).
- ⁸ V.D. Shafranov, Rev. Plasma Phys. 2, Consultants Bureau 1966.
- ⁹ N. Fisch, Phys. Rev. Lett. 41, 873 (1978).
- ¹⁰ C. Karney and N. Fisch, Phys. Fluids 22, 1817 (1979).
- ¹¹ B.A. Trubnikov, Sov. Phys. Dok. 3, 136 (1958).
- ¹² S. von Goeler et al., Princeton University, Plasma Physics Laboratory Report PPPL-1060 (1974).

FIGURE CAPTIONS

FIG. 1 Schematic of PLT and the lower hybrid system.

FIG. 2 Reflection vs. forward power before and after improvements were made to the coupler.

FIG. 3 Neutron emission with 420 kW of lower hybrid power on from 450 to 600 ms. The phase is $\Delta\phi = -90^\circ$ and the line average density is $1.6 \times 10^{13} \text{ cm}^{-3}$.

FIG. 4 Charge exchange spectrum during lower hybrid pulse. The symbols represent lines of sight at the indicated major radii of tangency.

FIG. 5 T_{i1} vs. time for 350 kW of rf, line average density = 1.9×10^{13} , $\Delta\phi = -135^\circ$, and $B_{TF} = 27 \text{ kG}$.

FIG. 6 Evolution of plasma current, loop voltage, plasma density, $\Lambda = \beta_0 + l_1/2$, OH primary, and equilibrium field current during a current drive shot. The rf power is 100 kW and it is on from 200 to 1000 ms. The Λ signal is derived from I_p and I_{EF} .

FIG. 7 (a) Plasma current ramp up with 370 kW of rf applied from 300 to 500 ms. The density is $\bar{n}_e = 3 \times 10^{12} \text{ cm}^{-3}$.

(b) Loop voltage for same shot.

FIG. 8 Theoretical spectrum of power per unit $n_{\parallel}$ vs. $n_{\parallel}$ for the launched lower hybrid wave on PLT. The phasing $\Delta\phi = -90^\circ$, and $n_{\parallel}$ is the parallel index of refraction

FIG. 9 Plasma current vs. time for 140 kW of rf on from 250 to 750 ms. Waveguide phasings are $\Delta\phi = -60^\circ$, -120° and -180° along with the no-rf case

FIG. 10 RF power vs. line average density for $\dot{I}_p = 0$. The plasma current is $I_p = 200$ kA, the waveguide phasing is $\Delta\phi = -90^\circ$, and the gas is deuterium.

FIG. 11 Enhancement of cyclotron emission (arbitrary units) as a function of line average density at various radii. The rf is on from 250 to 750 ms.

FIG. 12 (a) Hard X-ray spectrum with and without rf at a line average density $\bar{n}_e = 3 \times 10^{12} \text{ cm}^{-3}$. The inset shows the time evolution of the plasma X rays and the limiter X rays (inverted scale). RF power is 80 kW and is on from 300 to 700 ms.

(b) Hard X-ray spectrum with and without rf at a line average density $\bar{n}_e = 6 \times 10^{12} \text{ cm}^{-3}$. RF power is 200 kW and is on from 300 to 700 ms.

FIG. 13 (a) Electron body energy (kJ) vs. time during current drive at $\bar{n}_e = 5.7 \times 10^{12} \text{ cm}^{-3}$.

(b) Power input to the plasma from inductive sources and rf

#82X0165

Fig. 1

82X0167

Fig. 2

82X015t

Fig. 3

#81X0966

Fig. 4

Fig. 5

#82X0159

Fig. 6

Fig. 7

82X0162

Fig. 8

#82X0164

Fig. 9

Fig. 10

81X1315

ORDINARY MODE ECE $\omega = \Omega_{ce}$ EXTRAORDINARY MODE ECE $\omega = 2\Omega_{ce}$

Fig. 11

Fig. 12a

#82X0054

Fig. 12b

Fig. 13

EXTERNAL DISTRIBUTION IN ADDITION TO TIC UC-20

Plasma Res Lab, Austra Nat'l Univ, AUSTRALIA
 Dr. Frank J. Poolton, Univ of Wollongong, AUSTRALIA
 Prof. I.R. Jones, F. Inders Univ., AUSTRALIA
 Prof. M.H. Brennan, Univ Sydney, AUSTRALIA
 Prof. F. Cap, Inst Theo Phys, AUSTRIA
 Prof. Frank Verhaest, Inst theoretische, BELGIUM
 Dr. D. Palumbo, Oj XII Fusion Prog, BELGIUM
 Ecole Royale Militaire, Lab de Phys Plasmas, BELGIUM
 Dr. P.H. Sakonaka, Univ Estadual, BRAZIL
 Dr. C.R. James, Univ of Alberta, CANADA
 Prof. J. Telchmann, Univ of Montreal, CANADA
 Dr. H.M. Skarsgard, Univ of Saskatchewan, CANADA
 Prof. S.R. Greenlivan, University of Calgary, CANADA
 Prof. Tudor W. Johnston, INRS-Energie, CANADA
 Dr. Hannes Bernhard, Univ British Columbia, CANADA
 Dr. M.P. Bachynski, MPB Technologies, Inc., CANADA
 Zhenggu Li, SW Inst Physics, CHINA
 Library, Tsing Hua University, CHINA
 Librarian, Institute of Physics, CHINA
 Inst Plasma Phys, SW Inst Physics, CHINA
 Dr. Peter Lukec, Komenského Univ, CZECHOSLOVAKIA
 The Librarian, Culham Laboratory, ENGLAND
 Prof. Schatzman, Observatoire de Nice, FRANCE
 J. Redet, CEN-BP6, FRANCE
 M. Dupes Library, AM Dupes Library, FRANCE
 Dr. Tim Mual, Academy Bibliographic, HONG KONG
 Preprint Library, Cent Res Inst Phys, HUNGARY
 Dr. A.K. Sunderam, Physical Research Lab, INDIA
 Dr. S.K. Trehan, Panjab University, INDIA
 Dr. Indra, Mohan Lal Das, Banaras Hindu Univ, INDIA
 Dr. L.K. Chavda, South Gujarat Univ, INDIA
 Dr. R.K. Chhajlani, Var Ruchi Marg, INDIA
 B. Buti, Physical Research Lab, INDIA
 Dr. Phillip Rosenau, Israel Inst Tech, ISRAEL
 Prof. S. Cuperman, Tel Aviv University, ISRAEL
 Prof. G. Rostagni, Univ Di Padova, ITALY
 Librarian, Int'l Ctr Theo Phys, ITALY
 Miss Diella De Palo, Assoc EURATOM-CNEN, ITALY
 Biblioteca, del CNR EURATOM, ITALY
 Dr. H. Yamato, Toshiba Res & Dev, JAPAN
 Prof. M. Yoshikawa, JAERI, Tokai Res Est, JAPAN
 Prof. T. Uchida, University of Tokyo, JAPAN
 Research Info Center, Nagoya University, JAPAN
 Prof. Kyoji Nishikawa, Univ of Hiroshima, JAPAN
 Sigeru Mori, JAERI, JAPAN
 Library, Kyoto University, JAPAN
 Prof. Ichiro Kawakami, Nihon Univ, JAPAN
 Prof. Satoshi Itoh, Kyushu University, JAPAN
 Tech Info Division, Korea Atomic Energy, KOREA
 Dr. R. England, Ciudad Universitaria, MEXICO
 Bibliotheek, Fom-Inst Voor Plasma, NETHERLANDS
 Prof. B.S. Lilley, University of Waikato, NEW ZEALAND
 Dr. Suresh C. Sharma, Univ of Calabar, NIGERIA
 Prof. J.A.C. Cabral, Inst Superior Tech, PORTUGAL
 Dr. Octavian Petrus, ALI CUZA University, ROMANIA
 Dr. R. Jones, Nat'l Univ Singapore, SINGAPORE
 Prof. M.A. Hellberg, University of Natal, SO AFRICA
 Dr. Johan de Villiers, Atomic Energy Bd, SO AFRICA
 Dr. J.A. Tagle, JEN, SPAIN
 Prof. Hans Wilhelmsson, Chalmers Univ Tech, SWEDEN
 Dr. Lennart Stenflo, University of UMEA, SWEDEN
 Library, Royal Inst Tech, SWEDEN
 Dr. Erik T. Karlson, Uppsala Universitet, SWEDEN
 Centre de Recherches, Ecole Polytech Fed, SWITZERLAND
 Dr. W.L. Weise, Nat'l Bur Stand, USA
 Dr. W.M. Steacy, Georg Inst Tech, USA
 Dr. S.T. Wu, Univ Alabama, USA
 Mr. Norman L. Olsson, Univ S Florida, USA
 Dr. Benjamin Ma, Iowa State Univ, USA
 Magne Kristiansen, Texas Tech Univ, USA
 Dr. Raymond Askew, Auburn Univ, USA
 Dr. V.T. Tolok, Kharkov Phys Tech Ins, USSR
 Dr. D.D. Ryutov, Siberian Acad Sci, USSR
 Dr. M.S. Rabinovich, Lebedev Physical Inst, USSR
 Dr. G.A. Eliseev, Kurchatov Institute, USSR
 Dr. V.A. Glukhikh, Inst Electro-Physicat, USSR
 Prof. T.J. Boyd, Univ College N Wales, WALES
 Dr. K. Schindler, Ruhr Universitat, W. GERMANY
 Nuclear Res Estab, Jülich Ltd, W. GERMANY
 Librarian, Max-Planck Institut, W. GERMANY
 Dr. H.J. Kaeppeler, University Stuttgart, W. GERMANY
 Bibliothek, Inst Plasmeforschung, W. GERMANY