SPECTROSCOPIC DIAGNOSTICS OF TRITIUM RECYCLING IN TFTR

BY

C.H. Skinner, D.P. Stotler, H. Adler, A.T. Ramsey, et al.

Presented at the Tenth Topical Conference on
High Temperature Plasma Diagnostic Conference
Rochester, NY, 8-12 May, 1994

Work supported by U.S. Department of Energy Contract DE-AC02-76CH0-3073

Princeton University
Plasma Physics Laboratory

DISCLAIMER

Proceedings of the 10th Topical Conference on High Temperature Plasma Diagnostics
Rochester N Y, 8-12 May 1994

Spectroscopic Diagnostics of Tritium Recycling in TFTR.

C H Skinner, D P Stotler, H Adler, A T Ramsey,
Princeton University, Plasma Physics Laboratory,
P O Box 451, Princeton N J 08543.

We present the first spectroscopic measurements of tritium Balmer-alpha (T_α) emission from a fusion plasma. A Fabry-Perot interferometer is used to measure the H_α, D_α, T_α spectrum in the current D-T experimental campaign on TFTR and the contributions of H, D and T are separated by spectral analysis. The T_α line was measurable at concentrations $T_\alpha/(H_\alpha+D_\alpha+T_\alpha)$ down to 2%.

INTRODUCTION

D-T plasmas in TFTR[1] are typically fueled by neutral beams but hydrogenic ions, recycled from the limiter, are a major factor in plasma composition and reactivity. The recycling can be observed in Balmer-alpha emission from neutral hydrogen isotopes at the plasma edge.[2] The atomic velocities, arising from dissociation and charge exchange, are mapped in the Doppler broadened line profiles. The tritium Balmer-alpha (T_α) emission wavelength is slightly shifted from that of deuterium Balmer-alpha (D_α) by the small difference in the reduced mass of the nucleus/electron system and is at 6560.45Å compared to 6561.04Å for deuterium. This wavelength difference is a factor three smaller than the separation between H_α and D_α and is comparable to the Doppler width of the lines. The relative amount of *tritium*-alpha, $T_\alpha/(H_\alpha+D_\alpha+T_\alpha)$, is low even in plasmas with 100% tritium neutral beam injection because the recycled tritium influx is highly diluted by the pre-existing inventory of deuterium in the limiter. The experimental challenge is then to detect a small level of T_α that is blended into the D_α emission line. We report observations of the H_α, D_α, T_α spectra with a Fabry-Perot interferometer in which T_α emission at levels down to 2% of the total $(H_\alpha+D_\alpha+T_\alpha)$ was successfully detected.

I. EXPERIMENTAL SETUP

The experiment was conceived at the time TFTR was intensively involved with preparations for D-T operation and installation of new equipment on the machine was highly circumscribed. Fortunately an array of telescopes coupled by fiberoptics to a remote system of interference filters and detectors (dubbed HAIFA[3]), was in place to monitor the combined H_α, D_α emission and it was possible to use a spare channel in this system to bring light from the plasma to a data acquisition room situated 50M distant from the TFTR. Balmer-alpha emission occurs at the inner graphite limiter where the magnetic field of 7 Tesla causes the line to be split into two σ components displaced by $\pm$ 1.4Å polarized perpendicular to the field, and an undisplaced π component polarized parallel to the field. A sheet Polaroid polarizer was attached to the front of a telescope and oriented to transmit only the undisplaced π component.

The set up is shown in Fig. 1. Light from TFTR was collected by a telescope and transmitted via a 1mm diameter fiber optic to the data acquisition room. On exiting the fiber, the light from the plasma was recollimated, filtered with a 10Å bandpass filter and re injected to a second fiber. The maximum transmission wavelength of the filter was set to the D_α wavelength by a slight rotation of the filter. In this procedure a tungsten lamp and scanning monochromator were used to provide tunable light source and the filter transmission monitored on a chart recorder. A hydrogen discharge lamp was used for wavelength calibration of the monochromator.

A Fabry-Perot (Burleigh TL38) was used to spectrally resolve the H_α, D_α, T_α emission. The free spectral range of the Fabry-Perot was set to 7Å to encompass the complete H_α, D_α and T_α line spectrum. The finesse available from the existing mirror set was 30 giving a resolution of 0.23Å. Such a resolution is also potentially available from a large monochromator, however the Fabry-Perot has a major advantage in optical efficiency, being a fast, f3 system that can accept light from a 1mm optical fiber (no entrance slit is needed) and the resulting high signal/noise ratio is a key factor in detecting tritium at low concentrations. The Fabry-Perot itself is compact (60mm diameter and 60mm long), and has a fixed invar spacer between the mirrors. Coarse alignment is performed mechanically and three piezoelectric elements are used for fine alignment and temporal scanning. The Fabry-Perot was set to scan over two orders every 200msec (the lower limit is 20msec scan time/order) and the transmitted light conveyed via a fiber optic to an RCA R928 photomultiplier. Time variations in the overall H_α,D_α,T_α intensity in the plasma also modulate the Fabry-Perot signal. A beam splitter before the Fabry-Perot intercepted a small fraction of the light and reflected it back to a separate fiber that transmitted it to a second interference filter set to the D_α wavelength and a second photomultiplier. In this way the total H_α,D_α,T_α intensity from exactly the same collection volume was recorded and used to normalize the Fabry-Perot signal and obtain the spectral line profile. Two additional channels were used to monitor the piezo element driving voltages. The four signals were digitized at 2 kHz and archived for subsequent analysis.

To maintain high resolution it is necessary that any drift in the separation of the Fabry-Perot mirrors be less than 50Å. The instrument was housed in a chamber in which the temperature was maintained at 30° ±1°. However this, by itself, was not sufficient to maintain alignment for more than 5-10 hours. Since access to the data acquisition room was not possible during machine operations an automated system was implemented to maintain optimal alignment. A helium neon laser beam was used to provide a continuous optical reference signal. The beam was attenuated and input via a fiber optic to the exit telescope in the filter assembly. Some scattered laser light was transmitted along the signal fiber optic to the Fabry-Perot. This appeared in the scanned Fabry-Perot spectrum at a different order to the $H_\alpha D_\alpha T_\alpha$ signal. In a period of 0-7 seconds during a plasma discharge the laser beam was blocked. At other times the measured spectral profile of the laser light provided a continuous monitor of the instrumental resolution. The signal was used in an electronic controller (Burleigh DAS 10) to maintain Fabry-Perot alignment. The integrated signal in a 10msec time window (encompassing the whole laser line) was continually optimized by adjusting all three piezo element voltages in a feedback loop with a response of a few seconds. This maintained a constant mirror separation. The integrated signal in a smaller 2 msec time window at the line center was used in a slower feedback loop that simultaneously monitored trial variations in each piezo element in turn to maximize the line center signal and thus maintain optimal alignment. During the six seconds of the plasma discharge the laser and optimization process was automatically turned off. This system was able to maintain optimal Fabry-Perot alignment indefinitely.

II INITIAL RESULTS IN DEUTERIUM PLASMAS

The Fabry-Perot system was first used with discharges fueled by deuterium neutral beam injection (NBI) plus deuterium and a small amount of hydrogen recycled from the wall. Of particular interest in the observed $H_\alpha D_\alpha$ line profile was the extent and reproducibility of the line wing of the D_α profile at the T_α wavelength. Before tritium operation a 'preview' of the expected $H_\alpha D_\alpha T_\alpha$ spectrum was obtained by adding a simulated T_α line profile to the observed $H_\alpha D_\alpha$ line profile. An approximation to the T_α profile was constructed by manipulating the data elements of the short wavelength side of the observed D_α profile in a spreadsheet program to generate a complete profile that was shifted to the T_α wavelength and narrowed by a factor $\sqrt{(3/2)}$ due to the mass difference. Fig. 2 shows the result of adding this to an experimental $H_\alpha D_\alpha$ profile (taken with a 0.6mm dia. fiber). At concentrations above 20% a clear separate peak emerges, below that level, the T_α line is apparent in a displacement or 'bulge' in the side of the D_α profile. To estimate the level at which T_α would be detectable a line fitting program was used. This fit the complete $H_\alpha D_\alpha T_\alpha$ profile to 6 Gaussians, two Gaussians to each isotope, with some constraints from the known relation between the individual line shapes. From analysis of the Gaussians fits an estimate of the T_α concentration could be made and compared to the known fraction of simulated T_α added to the experimental $H_\alpha D_\alpha$ line. The results[4] were very promising, and showed good agreement between the input concentration and that estimated from the line fits.

The signal level was increased by increasing the fiber diameter from 0.6mm 0.1mm and using a faster lens. An additional factor in the sensitivity of this technique is the reproducibility of the $D_\alpha H_\alpha$ line profile. In the D-T campaign on TFTR significant effort was devoted to producing reproducible discharges so that the effects of tritium on the plasma parameters could be most clearly identified. This resulted in highly reproducible line profiles as can be seen in Fig. 3 which shows a comparison of two $H_\alpha D_\alpha$ profiles from different discharges. The difference in the line profiles, integrated over the area of the T_α line, was remarkably low (0.02%).

III RESULTS IN DEUTERIUM PLASMAS.

The first indication of T_α became apparent at the end of the first high power campaign (DT7) in discharge #73273. which used 100% tritium NBI. The preceding discharge #73272 was 100% deuterium NBI, and was used as a comparison discharge. When the line profiles from #73272 and #73273 were overlaid, a small but clear difference was apparent at the T_α wavelength, similar to a spectrum previously simulated with 2% tritium concentration. A more quantitative analysis using the line fitting program showed a 2% increase in the intensity of the profile at the D_α wavelength. The clearest evidence for T_α emission was obtained by numerically subtracting the line profile for the deuterium discharge from the tritium discharge, revealing a spectral line at the T_α wavelength with an area 2% of the total. In subsequent discharges in second high power D-T campaign (DT9) the level of T_α increased up to several percent. Interestingly, the maximum level of $T_\alpha/(H_\alpha+D_\alpha+T_\alpha)$ of 7.5% was in a deuterium NBI discharge immediately following tritium NBI; #74353 shown in Fig. 4. This discharge also exhibited anomalous MHD and sawteeth. Over the following remaining seven deuterium NBI discharges of the day, the T_α level decreased relatively slowly with a decay constant of 7.5 discharges.

An overlay of a T_α line profile calculated by the Monte-Carlo neutral transport code DEGAS is shown for comparison. When, through dissociation, excitation or charge exchange, a test particle emits an H_α photon in a volume corresponding to the observation volume, the particle velocity is logged and, over thousands of flights, a spectral line profile built up [5]. In the present comparison, the DEGAS profile used plasma parameters from an earlier supershot discharge (#72422), and the predicted profile was convoluted with the experimental instrument function. This first comparison shows overall harmony between the observed and predicted profiles. A more extensive account of the experimental results is given in reference [6]. The D-T experiments will provide a unique opportunity to study tritium edge physics. Further comparisons of the observed and predicted T_α line profiles are planned and will be reported in a subsequent paper.

ACKNOWLEDGMENTS

We would like to acknowledge the support of the TFTR team, especially the contributions of M. Bell, R V Budny, M. Caorlin, D. Johnson, L C Johnson, D. Mikkelsen and J. Strachan. The technical assistance of J. Bartolick, D. Cylinder, M. Diesso, G. Drodz, and P. Sichta is highly appreciated. This work was supported by the US. Department of Energy Contract No. DE-AC02-76-CH0307

REFERENCES:

[1] R J Hawryluk H Adler, P Alling *et al.* Princeton University, Plasma Physics Laboratory Report # PPPL 2977 (February 1994) 12pp, Phys Rev. Lett. in press; and J D Strachan H Adler, P Alling *et al* Plasma Physics Laboratory Report # PPPL 2978 (February 1994) 14pp, Phys Rev. Lett. in press.

[2] D H McNeil, *J. Nucl Mater.* **162** (1989) 476.

[3] A T Ramsey and S L Turner, *Rev. Sci. Instrum.* **58**, 1211 (1987).

[4] C H Skinner, A T Ramsey, D W Johnson and M Diesso; PPPL Report PPPL-2878, Feb. 1993.

[5] D P Stotler, C H Skinner, R V Budny, H Adler, and A T Ramsey, presented at the 1994 International fusion Theory Conference, Dallas, March 14-16, 1994 (Univ of Texas, Austin 1994) paper 2C-15.

[6] C H Skinner, H Adler, R V Budny, J Kamperschroer, L C Johnson, A T Ramsey,and D P Stotler; Plasma Physics Laboratory Report # PPPL 2993 (May 1994) 19pp.

Figure Captions

Fig. 1. Experimental Setup

Fig. 2. The lowest trace is the H_α, D_α spectrum observed in TFTR before tritium operations (discharge #69019). The upper traces simulate the addition of 6% and 24% T_α respectively.

Fig. 3. An overlay of line profiles from two deuterium discharges (#73443 and #73441) illustrating the excellent reproducibility of the D_α H_α line profile. The difference, magnified by four, is plotted in the lower trace. The vertical dashed line marks the wavelength of T_α at rest.

Fig. 4. Upper traces shows a comparison of the normalized line profiles from discharge #73448 in bold and an earlier deuterium comparison discharge before tritium NBI (#73443; thin trace). The displacement on the short wavelength side of the profile is due to T_α. The lower traces shows the difference between these profiles magnified by a factor four (scale on the right hand side), and (dotted) a T_α profile predicted by DEGAS. The difference profile was smoothed with a filter function to remove noise features beyond the instrumental spectral resolution.

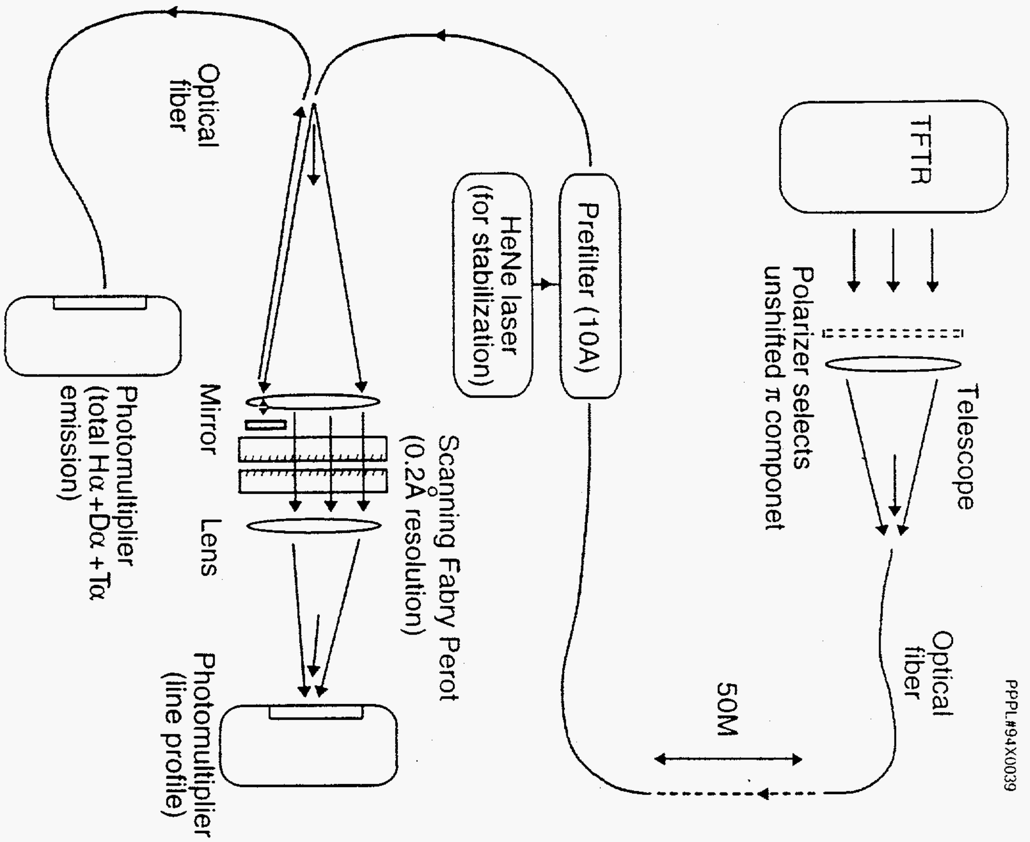

PPPL#94X0039
TFTR
Telescope
Polarizer selects
unshifted π componet
Optical
fiber
50M
Prefilter (10A)
HeNe laser
(for stabilization)
Optical
fiber
Scanning Fabry Perot
(0.2Å resolution)
Mirror
Lens
Photomultiplier
(line profile)
Photomultiplier
(total Hα+Dα+Tα
emission)

Fig. 1

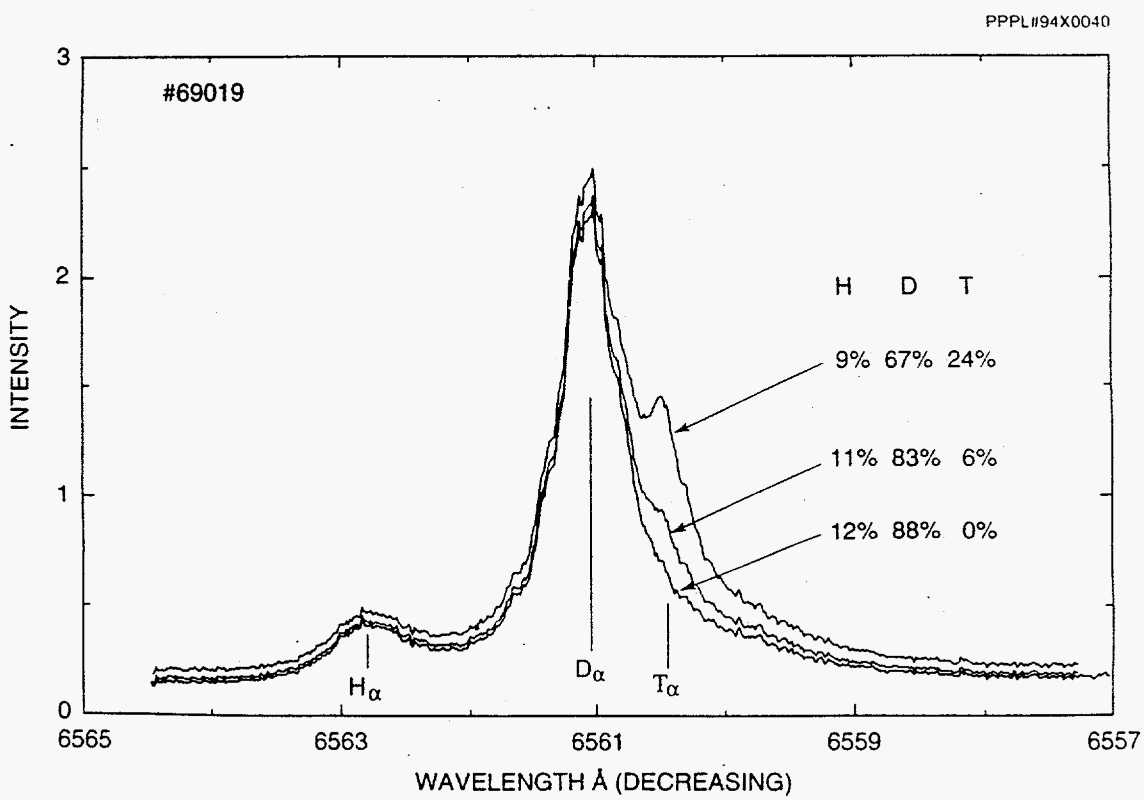
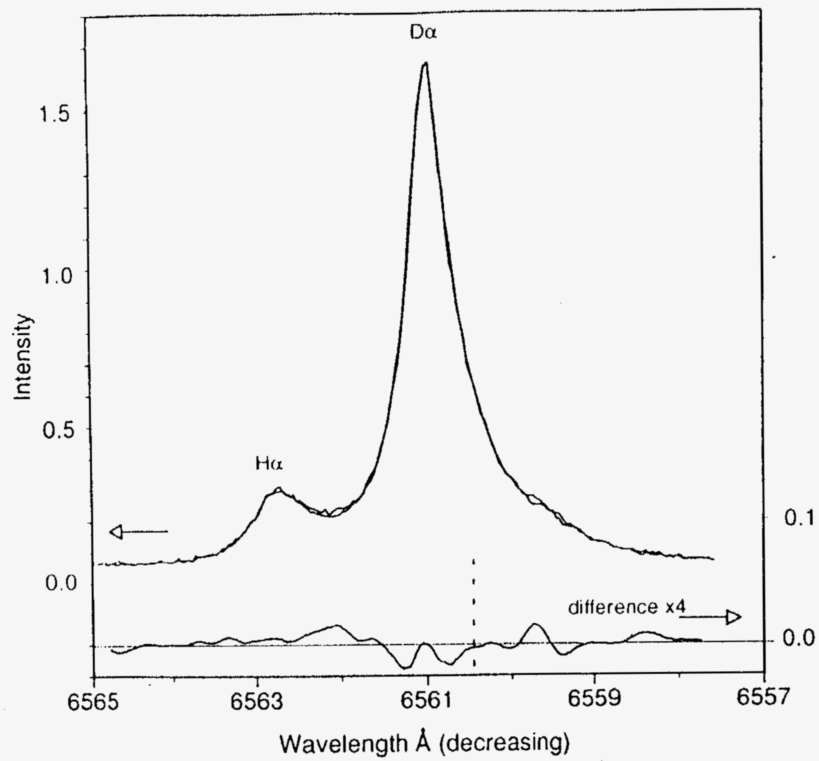
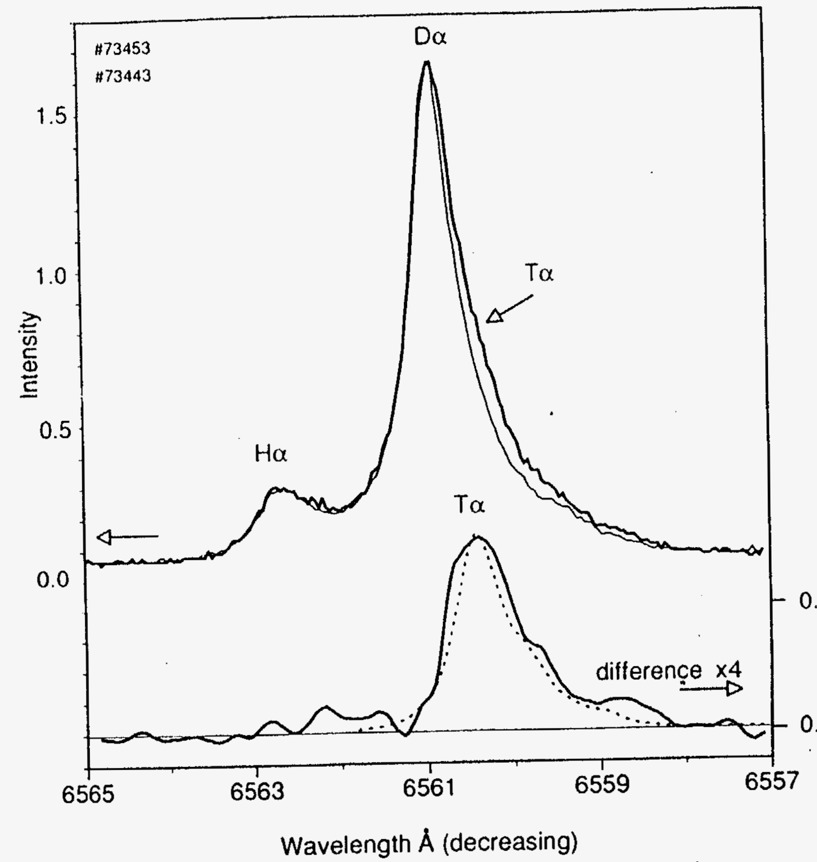

PPPL#94X0040
#69019
H D T
9% 67% 24%
11% 83% 6%
12% 88% 0%
Hα
Dα
Tα
INTENSITY
WAVELENGTH Å (DECREASING)
0
1
2
3
6565
6563
6561
6559
6557

Fig. 2



Dα
Hα
Intensity
1.5
1.0
0.5
0.0
0.1
0.0
difference x4
6565
6563
6561
6559
6557
Wavelength Å (decreasing)

Fig. 3



#73453
#73443
Dα
Tα
Hα
Tα
Intensity
1.5
1.0
0.5
0.0
0.1
0.0
difference x4
6565
6563
6561
6559
6557
Wavelength Å (decreasing)

Fig. 4

EXTERNAL DISTRIBUTION IN ADDITION TO UC-420

Dr. F. Paoloni, Univ. of Wollongong, AUSTRALIA
Prof. R.C. Cross, Univ. of Sydney, AUSTRALIA
Plasma Research Lab., Australian Nat. Univ., AUSTRALIA
Prof. I.R. Jones, Flinders Univ, AUSTRALIA
Prof. F. Cap, Inst. for Theoretical Physics, AUSTRIA
Prof. M. Heindler, Institut für Theoretische Physik, AUSTRIA
Prof. M. Goossens, Astronomisch Instituut, BELGIUM
Ecole Royale Militaire, Lab. de Phy. Plasmas, BELGIUM
Commission-European, DG. XII-Fusion Prog., BELGIUM
Prof. R. Boucique, Rijksuniversiteit Gent, BELGIUM
Dr. P.H. Sakanaka, Instituto Fisica, BRAZIL
Prof. Dr. I.C. Nascimento, Instituto Fisica, Sao Paulo, BRAZIL
Instituto Nacional De Pesquisas Espaciais-INPE, BRAZIL
Documents Office, Atomic Energy of Canada Ltd., CANADA
Ms. M. Morin, CCFM/Tokamak de Varennes, CANADA
Dr. M.P. Bachynski, MPB Technologies, Inc., CANADA
Dr. H.M. Skarsgard, Univ. of Saskatchewan, CANADA
Prof. J. Teichmann, Univ. of Montreal, CANADA
Prof. S.R. Sreenivasan, Univ. of Calgary, CANADA
Prof. T.W. Johnston, INRS-Energie, CANADA
Dr. R. Bolton, Centre canadien de fusion magnétique, CANADA
Dr. C.R. James,, Univ. of Alberta, CANADA
Dr. P. Lukác, Komenského Universzita, CZECHO-SLOVAKIA
The Librarian, Culham Laboratory, ENGLAND
Library, R61, Rutherford Appleton Laboratory, ENGLAND
Mrs. S.A. Hutchinson, JET Library, ENGLAND
Dr. S.C. Sharma, Univ. of South Pacific, FIJI ISLANDS
P. Mähönen, Univ. of Helsinki, FINLAND
Prof. M.N. Bussac, Ecole Polytechnique,, FRANCE
C. Mouttet, Lab. de Physique des Milieux Ionisés, FRANCE
J. Radet, CEN/CADARACHE - Bat 506, FRANCE
Prof. E. Economou, Univ. of Crete, GREECE
Ms. C. Rinni, Univ. of Ioannina, GREECE
Preprint Library, Hungarian Academy of Sci., HUNGARY
Dr. B. DasGupta, Saha Inst. of Nuclear Physics, INDIA
Dr. P. Kaw, Inst. for Plasma Research, INDIA
Dr. P. Rosenau, Israel Inst. of Technology, ISRAEL
Librarian, International Center for Theo Physics, ITALY
Miss C. De Palo, Associazione EURATOM-ENEA , ITALY
Dr. G. Grosso, Istituto di Fisica del Plasma, ITALY
Prof. G. Rostangni, Istituto Gas Ionizzati Del Cnr, ITALY
Dr. H. Yamato, Toshiba Res & Devel Center, JAPAN
Prof. I. Kawakami, Hiroshima Univ., JAPAN
Prof. K. Nishikawa, Hiroshima Univ., JAPAN
Librarian, Naka Fusion Research Establishment, JAERI, JAPAN
Director, Japan Atomic Energy Research Inst., JAPAN
Prof. S. Itoh, Kyushu Univ., JAPAN
Research Info. Ctr., National Instit. for Fusion Science, JAPAN
Prof. S. Tanaka, Kyoto Univ., JAPAN
Library, Kyoto Univ., JAPAN
Prof. N. Inoue, Univ. of Tokyo, JAPAN
Secretary, Plasma Section, Electrotechnical Lab., JAPAN
Dr. O. Mitarai, Kumamoto Inst. of Technology, JAPAN
Dr. G.S. Lee, Korea Basic Sci. Ctr., KOREA
J. Hyeon-Sook, Korea Atomic Energy Research Inst., KOREA
D.I. Choi, The Korea Adv. Inst. of Sci. & Tech., KOREA
Prof. B.S. Liley, Univ. of Waikato, NEW ZEALAND
Inst of Physics, Chinese Acad Sci PEOPLE'S REP. OF CHINA
Library, Inst. of Plasma Physics, PEOPLE'S REP. OF CHINA
Tsinghua Univ. Library, PEOPLE'S REPUBLIC OF CHINA
Z. Li, S.W. Inst Physics, PEOPLE'S REPUBLIC OF CHINA
Prof. J.A.C. Cabral, Instituto Superior Tecnico, PORTUGAL
Prof. M.A. Hellberg, Univ. of Natal, S. AFRICA
Prof. D.E. Kim, Pohang Inst. of Sci. & Tech., SO. KOREA
Prof. C.I.E.M.A.T, Fusion Division Library, SPAIN
Dr. L. Stenflo, Univ. of UMEA, SWEDEN
Library, Royal Inst. of Technology, SWEDEN
Prof. H. Wilhelmson, Chalmers Univ. of Tech., SWEDEN
Centre Phys. Des Plasmas, Ecole Polytech, SWITZERLAND
Bibliotheek, Inst. Voor Plasma-Fysica, THE NETHERLANDS
Asst. Prof. Dr. S. Cakir, Middle East Tech. Univ., TURKEY
Dr. V.A. Glukhikh,Sci. Res. Inst. Electrophys.I Apparatus, USSR
Dr. D.D. Ryutov, Siberian Branch of Academy of Sci., USSR
Dr. G.A. Eliseev, I.V. Kurchatov Inst., USSR
Librarian, The Ukr.SSR Academy of Sciences, USSR
Dr. L.M. Kovrizhnykh, Inst. of General Physics, USSR
Kernforschungsanlage GmbH, Zentralbibliothek, W. GERMANY
Bibliothek, Inst. Für Plasmaforschung, W. GERMANY
Prof. K. Schindler, Ruhr-Universität Bochum, W. GERMANY
Dr. F. Wagner, (ASDEX), Max-Planck-Institut, W. GERMANY
Librarian, Max-Planck-Institut, W. GERMANY