58/2114189 J.S. ①
PPPL-2592

UC-426,427

DR# 0600-9

PPPL-2592

A NEW ASYMMETRIC ABEL-INVERSION METHOD
FOR PLASMA INTERFEROMETRY IN TOKAMAKS

By

Hyeon K. Park

FEBRUARY 1989

REPRODUCED FROM
BEST AVAILABLE COPY

**PLASMA
PHYSICS
LABORATORY**

**PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY**

**PREPARED FOR THE U.S. DEPARTMENT OF ENERGY,
UNDER CONTRACT DE-AC02-76-CED-3073.**

ISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

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.

A New Asymmetric Abel-Inversion Method for Plasma Interferometry in Tokamaks

Hyeon K. Park

Plasma Physics Laboratory, Princeton University
Princeton, NJ 08543

Abstract

In order to get precise local electron density information from chordal interferometric measurement of a tokamak plasma, a self-consistent and reliable inversion method is necessary. In this paper, a new asymmetric Abel-inversion method is introduced. This method includes flexible boundary conditions, application to a non-circular geometry, and estimation of the plasma in the scrape-off layer. The advantages of this method are demonstrated by comparison with other methods. This new inversion method is applied to a parametric study which includes dependence on the Shafranov shift and elongation of the profile. The inverted results are integrated along different views and compared with other density measurements. This new method can also be applied to plasma spectroscopy.

MASTER

I. Introduction

The derivation of local electron density from chordal interferometric measurements in a tokamak plasma often encounters difficulty due to the different results produced by various asymmetric Abel-inversion methods. In this paper, a new asymmetric Abel-inversion method is introduced and compared to the results of conventional methods. In section II, the limitations of interferometry in a tokamak plasma are addressed. A brief description of two commonly used asymmetric Abel-inversion methods^{1,2} is given. These methods are tested for highly asymmetric and hollow electron density profiles where the differences between inversion methods are pronounced. Inconsistencies among existing inversion methods are demonstrated which result from intrinsic problems with each method. The new inversion method, which overcomes these problems and treats the inverted results self-consistently, is presented. In section III, a detailed description of the new inversion method for a tokamak plasma is given which includes an estimation of the Shafranov shift and the scrape-off density. The treatment of the in/out asymmetry of electron density along the flux surface is provided. Here, it is assumed that the asymmetric part of electron density, if it exists, is linearly distributed along the major axis. In section IV, this new method is also applied to plasmas with non-circular magnetic surfaces. The dependence of this method on Shafranov shift and elongation profile is investigated. In a practical application, the outermost flux surface elongation is correlated with poloidal beta. Conventional methods, which require rigid boundary conditions, often need an *ad hoc* assumption whereas the new method can avoid this assumption. The inverted profile is integrated along different views and compared with other measurements. In the last section, some of the important electron density parameters such as profile peakedness, peak density at the center of the flux surface, and line-integral density along any direction are discussed.

II. Interferometric Measurements and Inversion Methods

There are several limitations to vertical view interferometry: First, it assumes up-down symmetry. Second, the geometry must be determined from information such as magnetic measurements near the edge of the plasma un-

less the geometry is always circular. Finally, the presence of an edge density asymmetry (MARFE³) or internal MHD mode can complicate interpretation of the inverted results.

Discrepancies in the inverted results mostly come from incorrectly calculating the path length in the inversion process. This can be demonstrated for two cases: 1) hollow and highly asymmetric profiles and 2) two Abel-inversion processes; the slice-and-stack method¹ and the separation-of-variables method.²

The slice-and-stack method needs more than 200 points of line-integral data and two well-defined $\int n_e dl = 0$ boundary points. In practice, a spline fit or interpolation technique must be applied to this method. For a given line-density profile, a small density slab, δn_e ($=$ peak line average density divided by N , N is typically $\simeq 1000$) and the distance L_d between $\int n_e dl = 0$ boundary points can be constructed. The path length for each data point is based on a circle of diameter L_d . The quantity, $\delta n_e \times$ path length, can be subtracted from the line-integral data. Then the new boundary points, which are smaller than the first, can be found. This process continues until no line density is left. Meantime the small δn_e is stacked on each boundary point which becomes the density profile. For a peaked profile, this method is accurate as long as the density is constant on a flux surface. When this process encounters three $\int n_e dl = 0$ points (e.g., in the case of a hollow profile shown in Fig. 1a), it continues mapping to two smaller circles. Therefore, the flux surface based on this method consists, in the main, of shifted circles and two additional, smaller circles (see Fig. 7 in reference 1).

The essence of the separation-of-variables method is that the measured line-integrated density profile is the product of symmetric and asymmetric components. The symmetric part is inverted using a standard Abel-inversion method and the inverted result is multiplied by the asymmetric part as a weighting function (see Equations 5, 6, and 7 in reference 2). Here, an *ad hoc* assumption that the asymmetric part deduced from the line density profile is the same as the local density asymmetry is needed. Therefore the main geometry consists of concentric circles regardless of the Shafranov shift. For a larger shift, the expected errors could be larger. In fact, none of these assumptions may be applicable to realistic density profiles.

In Fig. 1a, the results of inversion of a hollow profile by the slice-and-stack (dashed line) and by the separation-of-variables (solid line) methods

are compared to the result of a new method (dot-dashed line), which is described in section III. In this plasma, the flux surfaces are circular and there is a small Shafranov shift. The slice-and-stack method shows an over-estimation of hollowness compared to the other two profiles. This result is expected due to the intrinsic inversion process for the hollow profile (e.g., the geometry consists of, in the main, circles and two additional smaller circles). On the other hand, the separation-of-variables method gives better agreement to the results of the new method because of the small shift and circular surface geometry. However, the asymmetries of the inverted density profile is still doubtful because of the estimation of the asymmetry based on an *ad hoc* assumption.

On the other hand, the plasma density profile of a supershot⁴ in the Tokamak Fusion Test Reactor (TFTR) is highly asymmetric due to a large Shafranov shift (up to 35 cm). As shown in Fig. 1b, the inverted density profile based on the separation-of-variables method (solid line) shows the worst agreement. This is expected due to the large shift. However, the slice-and-stack method (dashed line) is in good agreement with the results of the new method (dot-dashed line) except at the inner edge region and somewhat lower density across the profile. Since this method requires more than 200 points across the profile to invert and well-defined zero line-integral density points in order to estimate path length, the interpolation between the inner wall and the first data point requires *ad hoc* assumptions to avoid this bulge. The lower density across the profile compared to the result of the new inversion method is due to differences in geometry, which is discussed in detail in section IV.

The failure of conventional inversion methods in both cases is due to improper estimation of the path length and incorrect assumptions, whereas the new inversion method avoids these assumptions due to flexible boundary conditions and a self-consistent path length estimation.

III. New Inversion Method

As demonstrated in the previous section, an estimation of path length and preparation of line density profiles with appropriate boundary points are critical to the inversion process. In an ideal interferometer system, the minimum number of channels may be ~ 20 , with equal spacing across the

plasma including both inside and outside scrape-off regions. In practice, the number of chords and their spacing is limited due to accessibility. Furthermore, measurements of both the inside and outside scrape-off regions in a large tokamak are also limited for the same reason.

In the TFTR interferometry system,³ since the line density profile is based on a ten-channel measurement with uneven chord spacings, it is convenient to introduce a cubic spline fit with appropriate boundary conditions. Since the outermost flux surface is very close to the inner belt limiter, the innermost boundary point is chosen to be a linear extrapolation of two measured points (first and second data points from the inner belt limiter as shown in Fig. 2a). On the other hand, the outermost boundary point can be determined with better accuracy, since the last measured point is beyond the scrape-off layer. The variation of the inverted profile due to boundary conditions is examined later. In a system with ~ 20 chord measurements, the spline fit can be avoided.

The geometry is based on information from the line-integral density profile. However, elongation of the magnetic surface has been noticed in neutral-beam-heated, high-beta plasmas in contrast to the circular geometry of the ohmic phase. Here, the elongation (κ) is $\frac{a}{b}$ where a is the minor radius and b is the major radius in an ellipse. In order to account for the change in geometry from the ohmic to the beam-heated phase in the inversion, magnetic measurements near the plasma edge are needed. The correlation between poloidal beta (β_p) and surface elongation, which is discussed in detail in the next section, is used to obtain the geometry.

The measured interferometry signal can be written as

$$\int n_e(r) dl = N_e \cdot L$$

where $N_e = n_{e(n,m)}$ is the electron density matrix and $L = l_{n,m}$ is the path length matrix for the geometry shown in Fig. 2b. Here, n is the zone index and m is the subzone index. In principle, within measurement errors, the accuracy of the electron density matrix element is entirely dependent upon how the path length matrix is determined. The choice of n in this inversion method is flexible. If n is fixed, then the number of chords is always $2n$ and each chord is forced to pass through the center of its corresponding flux zone (along $l_{n,m}$) as depicted in Fig. 2b. In this example, $n = 10$, so that the number of chords is 20. The splined data (200 points) in Fig. 2a are reduced

to 20 by averaging. In case of 20 or more chordal measurements, a linear interpolation technique can be applied instead of a spline fit.

The measured line density profile includes information about the Shafranov shift as shown in Fig. 2a. Here, the center of the last flux surface is at ≈ 2.45 m whereas the peak of the line integral density profile is at ≈ 2.69 m. Even if the line density peak may not coincide with the peak of the innermost flux surface, the initial geometry can be constructed. In this inversion method, the center of the innermost flux surface can be found through iteration with an assumption that the density is constant in the innermost flux zone. For a hollow line-density profile (extreme hollow density profile), the iteration can start with the pre-assigned position of the innermost flux surface. The exact radial dependence of the Shafranov shift can be obtained from MHD equilibrium calculations for the given plasma conditions. In practice, the shift profile can be approximated as a parabola with some exponentiate factor on a flux surface. The dependences of this parameter are examined in the next section.

The geometry consists of ten circular (or elliptical) zones with a shifted center initially estimated from the position of the peak of the line-integrated density profile. Based on the above considerations, the path length matrix elements ($l_{n,m}$) can be calculated. Since this geometry is constructed within the last rational surface ($p = \frac{r}{a} = 1$), density at the scrape-off layer must be estimated and contributions are removed from each chord. As shown in Fig. 3a, the profile from the last flux surface to zero line-integral density is divided into 3 zones. The scrape-off layer can be modeled based on the last flux surface shape (circle or ellipse); one can calculate line-integral contributions to each chord. The results of this process are shown in Fig. 2c. The solid line is the measured line density for the 20 chords and the black circles are the calculated scrape-off contributions. The open circles are the line density profile within the rational surface.

The inversion process starts from the outer chord in each zone. The line-integrated densities for each chord can be expressed as follows;

$$\begin{aligned} (\int n_e dl)_1 &= n_{e(1,1)} l_{1,1} \\ (\int n_e dl)_2 &= n_{e(1,2)} l_{1,2} + n_{e(2,1)} l_{2,1} \\ &\dots\dots\dots \end{aligned}$$

$$\begin{aligned}
 \left(\int n_e dl \right)_{2n-1} &= n_{e(1,2n-1)} l_{1,2n-1} + n_{e(2,2n-2)} l_{2,2n-2} \\
 &\quad \dots \dots \dots \\
 \left(\int n_e dl \right)_{2n} &= n_{e(1,2n)} l_{1,2n}
 \end{aligned}$$

If the calculated electron densities $n_{e(1,1)}$ and $n_{e(1,2n)}$ of the first and last equations above are different, the difference is distributed linearly along the major axis in order to determine $n_{e(1,2)}, n_{e(1,3)}, \dots, n_{e(1,2n)}$. Since the electron density distribution along the same flux surface is poorly known, a linear distribution along the major axis is adopted. Cosine or other distributions can be used if necessary. Once the subzone densities ($n_{e(1,j)}$) in the first zone are determined, the same operation can be performed on the next zone to determine ($n_{e(2,j)}$) and so on. Finally, the central subzone densities $n_{e(n,1)}$ and $n_{e(n,2)}$ are compared. At this point, it is reasonable to assume that the electron density is constant in the central zone. If $n_{e(n,2)}$ is higher (lower) than $n_{e(n,1)}$, then the Shafranov shift is changed in 1 cm steps until these elements agree within $\sim 3\%$.

Once the geometry is fixed by iteration, the scrape-off density contribution can be treated asymmetrically. If the density distribution in the outermost zone is asymmetric ($n_{e(1,1)} \geq n_{e(1,2n)}$, or vice versa), it is also reasonable that radial transport guarantees that the density in the scrape-off layer is also asymmetric. The ratio ($n_{e(1,1)}/n_{e(1,2n)}$) can be multiplied by the density estimated for the scrape-off layer and linearly distributed along the major axis. The contributions from the asymmetric scrape-off density can be removed from each chord and the profile again inverted.

In Fig. 2d, the final inverted density profile is shown with three density points in the scrape-off layer. The in/out density asymmetry is found to be relatively small (less than $\sim 10\%$ at the highest asymmetry point).

IV. Parametric Dependences

No matter how elegant and precise the method is, it may be useless in practice if the inversion process is sensitive to geometric parameters such as the radial dependence of the Shafranov shift, the boundary conditions, and the elongation.

The radial dependence of the Shafranov shift profile in this calculation is approximated as follows:

$$Sha f(\rho) = \epsilon_o(1 - \rho^2)^\alpha,$$

where $\rho = \frac{r}{a}$ (normalized minor radius), ϵ_o is the Shafranov shift of the innermost flux surface, and α is the exponentiation factor. The inverted results in Fig. 3a show little change for substantial changes of ϵ_o (from $\epsilon_o=22$ cm to 30 cm). Also, the inverted profile is extremely stable to the variations of α (from 0.6 to 0.9) as depicted in Fig. 3b. For TFTR plasmas, $\alpha \simeq 0.75$ is optimum.

In order to test the effects of boundary conditions, three line-integral density profiles are constructed using different inner boundary conditions as shown in Fig. 4a. The three extrapolation points are: higher than the linear extrapolation value, zero density at the limiter position, and a linear extrapolation point. Since the geometry employed for the inversion is fixed, errors in the inverted profile are purely those in the density. The error propagation is suppressed very quickly and the linearly extrapolated results are the most reasonable, as shown in Fig. 4b.

One of the characteristics of highly shifted density profiles is the elongation of the outermost flux surface during the beam heating phase (as inferred from magnetic measurements). More precisely, MHD equilibrium calculations predict elongation at the outermost surface, $\kappa_o \simeq 0.89$, and elongation at the innermost flux surface, $\kappa_i \simeq 1.03$, for this profile. The surface elongation profile is approximated as follows:

$$Elong(\rho) = \kappa_o + (\kappa_i - \kappa_o)(1 - \rho^2)^\gamma,$$

where γ is an exponentiation factor. The result of the inversion (solid line) for the elongated surface is shown in Fig. 5a. The dotted line is the inverted result based on a circular geometry ($\kappa_o = 1$, and $\kappa_i = 1$) in this figure. The differences in inverted profiles are the result of the shorter path length when surface elongation is present. Similar to the case of the Shafranov shift, the dependence on elongation (from $\gamma = 0.6$ to $\gamma = 1.6$) is also negligible, as illustrated in Fig. 6b. For TFTR neutral-beam-heated plasmas, $\gamma \simeq 0.7$ is a suitable value. It would be very cumbersome if the elongation factor had to be calculated before the inversion. In practice, the last flux surface elongation

(κ_o) can be correlated with the poloidal beta (β_p) which is available from magnetic measurements as shown below.

$$\kappa_o = p \times \beta_p + q.$$

where p and q are empirical constants. The innermost value is set to $\kappa_i \simeq 1$. The density profile previously shown in Fig. 3d employed the following parameters: $\kappa_o = 0.89$, $\kappa_i = 1.03$, and $\gamma = 0.7$ for the elongated profile and $\epsilon_o = 25$ cm and $\alpha = 0.75$ for the Shafranov-shifted profile. The actual Shafranov shift (ϵ_o) calculated from the MHD equilibrium code was 26.7 cm for this profile, which is very close to the value determined by iteration. Together with the path length elements and scrape-off layer contribution, the measured line-integral density can be recovered consistently.

Finally, in order to have some confidence in the inverted results, the integration is performed along the horizontal direction and compared with the line-integrated density measured by a 1 mm interferometer.⁶ The comparison is given in Fig. 6a. The difference is less than $\sim 3\%$ during the neutral-beam-heating phase and less than $\sim 10\%$ during the ohmic phase before and after the neutral beam power is applied. The variation of the error is due to systematic errors in the TFTR interferometry system, which are $\sim 1.0 \times 10^{14} \text{ cm}^{-2}$.

V. Applications of the New Method

In this inversion method, the geometry and local density are determined self-consistently. Important information about the behavior of the plasma electron density behavior can be deduced, such as peak electron density at the center of a flux surface, the line-integral along any direction, the total number of electrons, total number of electrons in each flux zone, and the profile shape. Particularly, the density profile peakedness, defined as

$$P_{ne} = \frac{n_{eo}}{\langle n_e \rangle_{vol}},$$

where n_{eo} is the peak electron density, and $\langle n_e \rangle_{vol}$ is the volume-averaged electron density, is an extremely useful parameter during plasma heating and density perturbation experiments. The time-dependent behavior of peakedness, peak density, and horizontal line-integrated density for a neutral-beam-heated plasma are shown in Fig. 6b.

VI. Summary

In this paper, a new asymmetric, self-consistent, Abel-inversion method is introduced. The advantages are illustrated through comparison with other asymmetric inversion methods. Hollow and highly asymmetric profiles are used to illustrate deficiencies in each method. Discrepancies among the methods are demonstrated to result from wrong estimation of the path length. In the new inversion process, the global in/out asymmetry in an electron density distribution, if it exists, can be treated asymmetrically with the assumption of a linear distribution along the major axis. This inversion method can be applied to a non-circular geometry using additional magnetic measurements. The parametric study demonstrates that the new inversion method is extremely stable to most parameters: radial dependence of the Shafranov shift, magnetic surface elongation, and boundary conditions. In practice, magnetic surface elongations which occur in a high β plasma are correlated with the measured poloidal beta. As an application, the peakedness of the density profile is an extremely interesting parameter during plasma density perturbation studies and heating experiments. The new inversion method can be applied to plasma spectroscopy with additional information such as electron (ion) temperatures and impurity (Z_{eff}) profiles.

Acknowledgments

The author wishes to thank to Drs. R.J. Goldston, M.C. Zarnstorff, M.G. Bell, and N. Bretz who encouraged him and provided useful suggestions. Thanks also go to Drs. G. Taylor and D.K. Mansfield for the verification of interferometry data. This work was supported by U.S. DoE contract No. DE-ACO2-76-CHO-3073.

References

- ¹N. Gottardi(1979). J. Appl. Physics 50, 2647.
- ²Y. Yatsutomo, K. Miyata, S. Himeno, T. Enoto, and Y. Ozawa (1981).
IEEE Trans. on Plasma Science PS-9, 18.
- ³F.P. Boody, C.H. Bush, S.S. Medley, H.K. Park, and J.F. Schivell (1987).
J. of Nuclear Materials 145-147, 196
- ⁴J.D. Strachan and co-workers (1987). Phys. Rev. Lett. 58, 1004.
- ⁵D.K. Mansfield, H.K. Park, L.C. Johnson, H.M. Anderson, R. Chouinard,
V.S. Foote, C.H. Ma, and B.J. Clifton (1987). Appl. Optics 15, 4469.
- ⁶P.C. Efthimion, G. Taylor, W. Ernst, M. Goldman, M. McCarthy, H. Anderson, and N.C. Luhmann (1987). Rev. Sci. Instrum. 56, 908.

Figures

FIG. 1. Inverted profiles of three different techniques; separation-of-variables (—), new technique(---), slice-and-stack (- - -), (a) Hollow profile case (b) Highly asymmetric profile case.

FIG. 2. (a) Line density profiles based on nine-channel data (o) and two additional boundary points(●), (b) Circular geometry for the path length calculation, (c) Preparation of line-integrated data (—); 20 points of raw data. (●); scrape-off layer density contribution to each chord. (o); line density points within rational surface. (d) The inverted density profile with three scrape-off layer densities.

FIG. 3. (a) Shafranov shift dependences of inverted profiles ($\epsilon_0=22$ cm, 26 cm, and 30 cm), (b) Shafranov shift profile dependences ($\alpha=0.6, 0.7$, and 0.9).

FIG. 4. (a) Line-integrated density profiles with three different inner boundary conditions (b) Inverted results of corresponding line density profiles in (a).

FIG. 5. (a) The inverted results of circular (dotted line) and elongated (solid line) surfaces (b) The elongation profile dependence (from $\gamma=0.4, 1.0$, and 1.6).

FIG. 6. (a) Time dependence of the horizontal integration of the inverted profile (solid line) and the measured line density by 1 mm interferometer (dotted line) during neutral beam heating. (b) Time dependent density profile peakedness (P_{ne}), peak electron density (n_{eo}), and horizontally integrated density during neutral beam heating.

Fig. 1 (a)

Fig. 2(a)

Fig. 2(b)

Fig. 2(c)

Fig. 2(d)

Fig. 3(a)

Fig. 3(b)

#88X0665

Fig. 4(a)

Fig. 4(b)

Fig. 5(a)

Fig. 5(b)

Fig. 6(a)

Fig. 6(b)

EXTERNAL DISTRIBUTION IN ADDITION TO LC-20

Dr. Frank J. Paoloni, Univ of Wollongong, AUSTRALIA
 Prof. M.H. Brennan, Univ Sydney, AUSTRALIA
 Plasma Research Lab., Australian Nat. Univ., AUSTRALIA
 Prof. I.R. Jones, Flinders Univ., AUSTRALIA
 Prof. F. Cap, Inst Theo Phys., AUSTRIA
 Prof. M. Heindler, Institut für Theoretische Physik, AUSTRIA
 M. Goossens, Astronomisch Instituut, BELGIUM
 Ecole Royale Militaire, Lab de Phys Plasmas, BELGIUM
 Commission-European, Dg-XII Fusion Prog, BELGIUM
 Prof. R. Boucique, Laboratorium voor Natuurkunde, BELGIUM
 Dr. P.H. Sakanaka, Instituto Fisica, BRAZIL
 Instituto De Pesquisas Espaciais-INPE, BRAZIL
 Documents Office, Atomic Energy of Canada Limited, CANADA
 Dr. M.P. Bachynski, MPB Technologies, Inc., CANADA
 Dr. H.M. Skarsgard, University of Saskatchewan, CANADA
 Dr. H. Barnard, University of British Columbia, CANADA
 Prof. J. Teichmann, Univ. of Montreal, CANADA
 Prof. S.R. Sreenivasan, University of Calgary, CANADA
 Prof. Tudor M. Johnston, INRS-Energie, CANADA
 Dr. C.R. James, Univ. of Alberta, CANADA
 Dr. Peter Lukac, Komenského Univ, CZECHOSLOVAKIA
 The Librarian, Culham Laboratory, ENGLAND
 The Librarian, Rutherford Appleton Laboratory, ENGLAND
 Mrs. S.A. Hutchinson, JET Library, ENGLAND
 C. Moutter, Lab. de Physique des Milieux Ionisés, FRANCE
 J. Rader, CEN/CADARACHE - Bat 506, FRANCE
 Univ. of Ioannina, Library of Physics Dept. GREECE
 Dr. Tom Muai, Academy Bibliographic Ser., HONG KONG
 Preprint Library, Hungarian Academy of Sciences, HUNGARY
 Dr. B. Dasgupta, Saha Inst of Nucl. Phys., INDIA
 Dr. P. Kaw, Institute for Plasma Research, INDIA
 Dr. Philip Rosenau, Israel Inst. Tech, ISRAEL
 Librarian, Int'l Ctr Theo Phys, ITALY
 Prof. G. Rostagni, Univ Di Padova, ITALY
 Miss Clelia De Paio, Assoc EURATOM-ENEA, ITALY
 Biblioteca, Instituto di Fisica del Plasma, ITALY
 Dr. H. Tanato, Toshiba Res & Dev, JAPAN
 Prof. J. Kawakami, Atomic Energy Res. Institute, JAPAN
 Prof. Kyoji Nishikawa, Univ of Hiroshima, JAPAN
 Direc. Dept. Large Tokamak Res, JAERI, JAPAN
 Prof. Satoshi Itoh, Kyushu University, JAPAN
 Research Info Center, Nagoya University, JAPAN
 Prof. S. Tanaka, Kyoto University, JAPAN
 Library, Kyoto University, JAPAN
 Prof. Nobuyuki Inoue, University of Tokyo, JAPAN
 S. Mori, JAERI, JAPAN
 Librarian, Korea Advanced Energy Res. Institute, KOREA
 Prof. D.I. Choi, Adv. Inst Sci & Tech, KOREA
 Prof. B.S. Liley, University of Waikato, NEW ZEALAND
 Institute of Plasma Physics, PEOPLE'S REPUBLIC OF CHINA
 Librarian, Institute of Phys., PEOPLE'S REPUBLIC OF CHINA
 Library, Tsing Hua University, PEOPLE'S REPUBLIC OF CHINA
 Z. Li, Southwest Inst. Physics, PEOPLE'S REPUBLIC OF CHINA
 Prof. J.A.C. Cabral, Inst Superior Tecnico, PORTUGAL
 Dr. Octavian Petru, AL I CUZA University, ROMANIA
 Dr. Johan de Villiers, Fusion Studies, AEC, SO AFRICA
 Prof. M.A. Hellberg, University of Natal, SO AFRICA
 C.I.E.M.A.T., Fusion Div. Library, SPAIN
 Dr. Lennart Stenflo, University of UMEA, SWEDEN
 Library, Royal Inst Tech, SWEDEN
 Prof. Hans Wilhelmson, Chalmers Univ Tech, SWEDEN
 Centre Phys des Plasmas, Ecole Polytech Fed, SWITZERLAND
 Bibliotheek, Fon-inst Voor Plasma-Fysica, THE NETHERLANDS
 Dr. D.D. Ryutov, Siberian Acad Sci, USSR
 Dr. G.A. Eliseev, Kurchatov Institute, USSR
 Dr. V.A. Glukhikh, Inst Electrophysical Apparatus, USSR
 Dr. V.T. Tolok, Inst. Phys. Tech. USSR
 Dr. L.M. Kovrizhnykh, Institute Gen. Physics, USSR
 Nuclear Res. Establishment, Julich Ltd., W. GERMANY
 Bibliothek, Inst. Für Plasmaforschung, W. GERMANY
 Dr. K. Schindler, Ruhr Universität Bochum, W. GERMANY
 ASDEX Reading Rm, IPP/Max-Planck-Institut für
 Plasmaphysik, W. GERMANY
 Librarian, Max-Planck Institut, W. GERMANY
 Prof. R.K. Janov, Inst Phys, YUGOSLAVIA