MEASUREMENTS OF FUSION PRODUCT EMISSION
PROFILES IN TOKAMAKS

PPPL--2394

DE87 005628

J.D. STRACHAN, W.W. HEIDBRINK, H.W. HENDEL, J. LOVBERG,
T.J. MURPHY, E.B. NIESCHMIDT, G.D. TAIT, and S.J. ZWEBEN

Princeton University
Plasma Physics Laboratory
Princeton, New Jersey 08544 USA

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.

ABSTRACT

The techniques and results of fusion product emission profile measurements are reviewed. While neutron source strength profile measurements have been attempted by several methods, neutron scattering is a limitation to the results. Profile measurements using charged fusion products have recently provided an alternative since collimation is much easier for the charged particles.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

1.0 INTRODUCTION

Present-day tokamak experiments often have reasonably large populations of ions with energies up to ≈ 100 keV. One consequence is the detectable levels of several fusion reactions (Eq. 1) and the resultant diagnostic capability of understanding plasma ion behavior by measurement of the fusion products.

The focus of this paper is on the measurement of the spatial profile of the fusion reaction rate. Fusion product profile measurements would be particularly valuable in determining the location of energetic ion tails created by auxiliary heating, in evaluating the ion energy balance, and in determining particle transport. The utility of such measurements is illustrated in Fig. 1, which shows the dd fusion profile calculated from the $H^0 + D^+$ ion temperature profiles for DIII /1/. In that paper, R. Groebner et al., made the important discovery that the ion temperature profile is narrower than expected neoclassically. The experimental data is based upon the Doppler broadening of impurity lines which ultimately means the measurement of about 20% narrower experimental line widths than expected from neoclassical theory. The temperature difference at 1.7 m in DIII implies that fusion product emission levels (Fig. 1) would differ by a factor of 20. Thus fusion product profile measurements have the potential to sensitively diagnose the ion energy balance.

Neutron profile measurements have been attempted on several tokamaks, which have indicated the location of the peak neutron emission but have not specified profile details. Recently, detection of the charged reaction products (e.g., 14.7 MeV p, 3.7 MeV α , 3 MeV p, and 1 MeV t) have been made again after initial efforts /2/ about 25 years ago. Charged particle profile measurements /3,4/ have the principal advantage of much simpler collimation. This is presently an active area of research with several schemes being evaluated experimentally.

2.0 FUSION NEUTRON EMISSION PROFILES

A. Neutron Collimation

Neutron collimation is conceptually simple and involves shielding against all neutrons except those along a collimated line of sight. The principal difficulty is that neutrons are absorbed poorly in materials so that typical absorption lengths (Fig. 2) require large and massive neutron collimators (Fig. 3). A typical neutron shield made of paraffin has a 1m linear dimension for 2.5 MeV neutrons and a 3m linear dimension for 14.1 MeV neutrons. Clearly, such shielding is costly and consumes valuable space around the experiment. The TFTR multichannel neutron collimator (Fig. 3) weighs about 50 tons and is composed mostly of concrete /7/. Radioactive source calibrations indicate potentially good resolution in each channel, although results are not yet available from TFTR plasmas.

The best published results come from Alcator A /8/ where a water-filled neutron collimator with a single neutron collimation channel was scanned

shot-to-shot across a lower-hybrid-heated plasma (Fig. 4). The profile clearly indicates that the neutron emission arises from the plasma center but does not yield details of the profile. Of particular concern is the background level (shaded region in Fig. 4) which is within a factor-of-two of all of the off-axis data points. The background level arises from neutrons scattering from the vessel components into the collimator and scattering off the collimator throat. This noise level is discouraging since a neutron spectrometer (NE 213 liquid scintillator) was used in the Alcator experiment. The neutron spectrometer should provide relatively good discrimination against lower energy scattered neutrons.

B. Recoil Proton Directional Detection

A nuclear emulsion technique has been used on PLT /9/ and ASDEX /10/. The basic idea (Fig. 5) is to record the direction of full energy (2.5 MeV) recoil protons. Since these recoil protons will be traveling in the same direction as the incident neutron, chords of neutron emissivity can be determined. The principal limitation to this method is the weak cosine-squared dependence of the recoil proton energy (Fig. 5). Even with good energy resolution of the recoil protons, the neutron could have a significant range of incident directions and the resultant spatial resolution is poor. Typical emulsions have $\sim 10\%$ energy resolution, indicating that the incident neutron direction is determined to about 20° . Thus for an emulsion mounted at the vacuum vessel, the spatial resolution is only $\sim 25\%$ of the plasma diameter (Fig. 5). The emulsion data are time integrated and tedious to analyze. It is possible to make the detector time-resolved /11/ by using thin scintillator sheets (Fig. 6) and recording only the largest energy pulses which should

arise from neutrons travelling in the same direction as the thin sheet. Such systems have not been attempted since the resolution is fundamentally limited by the hydrogen neutron scattering kinematics (Fig. 5). A further degradation of the spatial resolution occurs at high ion temperatures or with non-thermonuclear neutron emission where the energy spread of the neutron emission is significant. Profile results (Fig. 7) from PLT /9/ using the emulsion technique indicate that the neutron emission arises from the plasma center but details of the profile are not resolved, as was the case for direct neutron collimation (Fig. 4).

C. ^3He Cloud Chamber

A similar technique was proposed for T-10 /12/ which could yield higher spatial resolution. Measurement of the track lengths and direction of the proton and triton from the $^3\text{He}(n,p)t$ nuclear reaction in a ^3He cloud chamber would accurately determine the energy and direction of the incident 2.45 MeV neutron (Fig. 8). If the neutron energy is known, then measurement of the angle between the proton and triton accurately determines the angle between the proton and incident neutron and thus gives the neutron direction. The projected accuracy of determining the neutron chords could be as good as 5% of the plasma diameter for a cloud chamber mounted at the vacuum vessel, but such an experiment has yet to be tried. One difficulty is that the amount of ^3He is large (\$500 k U.S.) and is susceptible to loss by accidental venting. A second difficulty is in the data analysis where only about 0.01% of the recorded tracks would be useful since most of the tracks are due to thermal neutrons.

3.0 PROFILE DATA DEDUCED FROM CHARGED FUSION PRODUCTS

An essential requirement for a profile measurement is that the energetic charged fusion product to be detected must be poorly confined and drift directly out of the device. For machines the size of PLT, the 3.0 MeV proton, 1.0 MeV triton, and 3.5 MeV alpha particle are useful for profile measurements since these particles readily escape, and their gyrodiameters are much smaller than the plasma radius. For TFTR, the 14.7 MeV proton orbit is suitable for profile measurements; but the lower energy particles tend to be too well confined. Unconfined banana-trapped particles are the most useful for profile measurements since they have low parallel velocities and thus are relatively insensitive to the poloidal magnetic field /3/. Typical grad-B drift velocities are in the range of 10^7 cm/sec so that the transit time from the plasma center to the vessel wall is in the range of 10 μ sec. or of the order of 10^{-2} of a collision time. This class of particles leaves the plasma promptly without interacting with the plasma.

The principal advantage of attempting profile measurements using charged fusion products was shown in Fig. 2, which indicates that the range of the charged particle in matter is much smaller than the absorption length of fusion neutrons. Practically, this means that collimators can be constructed with millimeter absorber thicknesses compared to the meter shielding dimensions required for neutrons (Fig. 3).

The chief disadvantage of using the charged fusion products for profile measurements is the complex nature of the orbits and the impact of the gyrodiameter on the spatial resolution. If the emissivity profile is flat, then the position uncertainty is about equal to the gyrodiameter. In many actual cases (Fig. 1), the profiles are so steep that the counts for each

detector reflect emission from only the small portion of the accepted orbits nearest to the plasma center.

A. Multiple Detectors

Initial attempts at profile measurements on PLT /3,13,14/ involved the use of multiple detectors. The array of collimated, silicon surface barrier detectors viewed a set of curved vertical chords to detect any 3 MeV proton born along these paths with the correct initial velocity (Fig. 9). Measurements were made during ohmic heating /3/, $D^0 + D^+$ neutral beam heating (Fig. 10), and during lower hybrid heating /14/. The experimental uncertainties are sufficiently small to make the data in Fig. 10 comparable in accuracy to other measurements but the data did not resolve the differences between the theoretical calculations of the neutral beam deposition /15/ and the charge-exchange recombination measurements /16/. The horizontal error bars are due primarily to the large radial extent of the 3 MeV proton gyroradii (Fig. 9).

One difficulty with multiple detectors is the need for a large number of ports which need to be individually aligned to high accuracy. Relative positioning uncertainties (especially in pitch angle) were large and this led to the use of single detector housings where relative alignment can be done more accurately. An array of the multiple detectors has been used on TFTR for measurement of the 14.7 MeV protons /17/ where the ratio of gyrodiameter to machine size is the same as for the 3 MeV protons on PLT.

B. Pitch Angle Resolution

A complete profile measurement /18/ was obtained on PLT using a single detector (Fig. 11) placed at the edge of the plasma. The recording element in this experiment is a CR-39 plastic nuclear track detector /19/ which detected escaping 3.7 MeV alphas created by $d(^3\text{He},p)\alpha$ fusion reactions during ICRF heating of a minority ^3He population. Etching of the CR-39 showed the location of the time-integrated alpha bombardment. Vertical displacement of the track location corresponds to a resolution of the gyroradius of the escaping particles implying an energy resolution of the escaping alphas of about 3 MeV/mm for the detector in Fig. 11. Horizontal displacement of the track locations on the plastic corresponds to pitch angle resolution of the escaping particles.

Pitch angle resolution of these particles corresponds to spatial resolution from the plasma (Fig. 12b). Essentially the different pitch angles are caused by different parallel velocities of each particle and the different parallel velocities are displaced in a major radius by the tokamak's poloidal magnetic field. The spatial resolution in the vicinity of the peak emission (near the RF resonance layer) was limited to approximately the gyrodiameter of the escaping alpha particles (Fig. 12).

A similar system /20/ is being evaluated on TFTR for measurement of the 3.5 MeV alpha from the $D(t,n)\alpha$ fusion reaction. In order to obtain time resolution in the 10 msec range, the CR-39 plastic has been replaced by a ZnS scintillator screen (Fig. 13) whose image is relayed to a camera or a set of photomultipliers. This scheme has been successfully tested on TFTR using escaping 1 MeV tritons from the $d(d,p)t$ fusion reaction.

An interesting feature of the pitch angle pattern expected for 3.5 MeV

alphas in TFTR is that the detector should receive no signal from the plasma center where the alphas are expected to be confined/4/. In this case (Fig. 13), the signal pattern should have a discontinuity at the pitch angle corresponding to the boundary between confined and unconfined alphas. The magnitude of the discontinuity depends on the alpha source profile and the pitch angle depends on the current profile. Furthermore, anomalous alpha losses should appear as a signal pattern enhanced at various pitch angles. For the case of anomalous alpha transport without much pitch angle scattering, a large enhanced signal should appear at the pitch angle of the discontinuity as the alphas are radially transported to the location of neoclassical orbit loss.

C. Gradient Measurements

Often in tokamaks (Figs. 1 and 12) the fusion emissivity is a steep function of position varying as much as an order of magnitude in a few centimeters. In this situation, the charged reaction products are useful for determining the local gradient in the fusion reactivity and thus the local ion temperature gradient and the local ion thermal conductivity /21,22/. The local gradient in the 3 MeV proton $d(d,p)t$ emission has been determined recently on PLT using a silicon surface barrier detector behind a collimator which allows three slightly different pitch angles to enter (Fig. 14). Each pitch angle resolves orbits which are displaced only slightly. The particles which pass through each angle are identified by pulse height analysis (Fig. 15). The 3 MeV protons are separated in pulse height by reducing their energy with different thickness foils in front of each angled collimator hole (Fig. 14). The relative counts in the three peaks (Fig. 15) give a measure of the

gradient in the dd reactivity. By using three single channel analyzers, the time evolution of the gradient can be determined. A similar design was also attempted on TFR /23/ to determine the source profile but was not adequately collimated to view only a steep gradient portion of the profile.

D. Coincidence Measurements

Potentially, an enormous improvement in spatial resolution could be obtained by detecting the two products of a single fusion reaction in coincidence. Such a technique is illustrated conceptually in Fig. 16 using the $d(^3\text{He},p)\alpha$ fusion reaction in TEXT. The 14.7 MeV proton detector would be collimated to see reactions only along a particular sight-line and an array of alpha-particle detectors (Fig. 16) would count in coincidence and would determine the spatial location of the fusion reaction as the intersection of the two orbits. One problem in such an experiment would be random coincidence events due to the possibly large alpha and proton non coincident count rates. Calculations indicate that useful coincidence measurements are possible for devices the size of TFR or TEXT but would be difficult on TFTR due to the random coincidence events /24/.

4.0 SUMMARY

While fusion reaction profile measurements are feasible with neutron diagnostic techniques, published data have been useful mainly to locate the peak emissivity. Recently, charged fusion product measurements have provided additional profile data. Advanced techniques are under development which could substantially improve the accuracy of these measurements.

ACKNOWLEDGMENTS

The authors would like to thank K.M. Young and the JETP Diagnostics Group for their support. This work was supported by U.S. DoE Contract No. DE-AC02-76-CHO-3073.

REFERENCES

- /1/ GROEBNER, R.J., et. al., Nucl. Fus. 26, 543 (1986).
- /2/ JONES, W.M., YOUNG, K.M., BARNARD, A.C.L., Plasma Phys. 3, 8 (1961).
- /3/ HEIDBRINK, W.W. and STRACHAN, J.D., Rev. Sci. Instr. 56, 501 (1985).
- /4/ KARULIN, K.E., and PUTVINSKY, S.V., Nucl. Fus. 25, 961 (1985).
- /5/ LITTMARK, V., "Handbook of Range Distributions for Energetic Ions in All Elements," (Pergamon, New York, 1980).
- /6/ "Neutron Cross Sections", BNL 325 Suppl., (Brookhaven, 1960).
- /7/ HENDEL, H.W., et. al., Rev. Sci. Instr. 56, 1081 (1985).
- /8/ SCHUSS, J.J., et. al., Nucl. Fus. 21, 441 (1981).
- /9/ STRACHAN, J.D., et. al., Phys. Lett. 66A, 295 (1978).
- /10/ HUBNER, K., Private communication.
- /11/ STRACHAN, J.D. and BATTACHARJEE, A., PPPL-TM-322 (1978).
- /12/ ZAVERIAEV, A., Private communication.
- /13/ HEIDBRINK, W.W., PhD. Thesis, Princeton Univ. (1984).
- /14/ HEIDBRINK, W.W., et. al., Plasma Phys. 28, 871 (1986).
- /15/ GOLDSTON, R.J., PhD. Thesis, Princeton Univ. (1977).
- /16/ SUCKEWER, S., et. al., Appl. Phys. Lett. 45, 236 (1984).
- /17/ STRACHAN, J.D., Rev. Sci. Instr. 57, 1771 (1986).
- /18/ MURPHY, T.J., and STRACHAN, J.D., Nucl. Fus. 25, 383 (1985).
- /19/ MUHLING, E., SCHUMACHER, V., and PARETZKE, H.G., Nucl. Tracks 9, 113 (1984).
- /20/ ZWEBEN, S.J., Rev. Sci. Instr. 57, 1774 (1986).
- /21/ HEIDBRINK, W.W., et. al., PPPL-2315 (1986).
- /22/ LOVBERG, J., STRACHAN, J.D., and HEIDBRINK, W.W., Radiat. Eff. (to be published).

/23/ MARTIN, G., Ph.D. Thesis, Fontenay-aux Roses (1985).

/24/ MURPHY, T.J., HEIDBRINK, W.W., and STRACHAN, J.D., Rev. Sci. Instr. 57,
1766 (1986).

FIGURE CAPTIONS

- Fig. 1 Predicted dd fusion emissivity profiles (error bars) for DIII /1/. The solid lines in the neoclassical ion energy balance prediction for DIII. The circles are the neoclassical prediction at the spatial location of the DIII ion temperature measurements /1/.
- Fig. 2 Proton and alpha ranges /5/ and exponential neutron absorption lengths /6/ for these energetic particles in iron.
- Fig. 3 Schematic diagram of the TFTR multichannel neutron collimator /7/.
- Fig. 4 Radial profile of the Alcator A 2.5 MeV neutron emission obtained using a water-filled neutron collimator /8/.
- Fig. 5 Proton energy as a function of the angle between the incident 2.5 MeV neutron and the measured direction of the recoil proton. The spatial resolution is for an emulsion mounted at the vacuum vessel and is expressed as a fraction of the plasma diameter.
- Fig. 6 Required detector thickness, d , for a specified resolving angle (and thus spatial resolution) assuming the detector is a thin sheet of plastic scintillator with energy resolution of about 5% /11/.
- Fig. 7 Radial profile of the $d(d,n)^3\text{He}$ fusion neutron emission obtained on PLT /9/ using the nuclear emulsion technique.

Fig. 8 Angle between the proton and triton resulting from a 2.45 MeV neutron-induced $^3\text{He}(n,p)t$ reaction in a ^3He cloud chamber. The measured direction of the proton track and the angle between the proton and neutron inferred from the diagram determines the direction of the incident neutron /12/.

Fig. 9 Poloidal projection of 3 MeV proton orbits in PLT. Each detector could count 3 MeV protons born along this trajectory that had the correct initial pitch angle and gyrophase to allow it to reach the detector /3,13/.

Fig. 10 3 MeV proton emissivity profile during $\text{D}^0 + \text{D}^+$ neutral beam heating in PLT /14/. The shaded region is the theoretical calculation /15/ and the solid line shows charge exchange recombination measurements /16/. The dotted lines indicate measurement of the emission gradient obtained by in-out motion of the plasma column.

Fig. 11 Schematic of the PLT escaping alpha detector showing the relative placement of the pinhole, slit, and CR-39 plastic /18/.

Fig. 12 a. Spatial profile of the d^3He fusion emissivity as determined by pitch angle resolution of the escaping 3.7 MeV alphas /18/.
 b. Pitch angle of the detected alphas as a function of the major radius of their guiding-center midplane crossing. This curve relates the signal level at a pitch angle to the plasma position in Fig. 12a.

Fig. 13 Schematic diagram of the TFTR escaping alpha detector which features time resolution achieved by imaging of a ZnS scintillator screen. For classical alpha particles, projected pitch-angle resolved signals will yield profile information only from the outer plasma regions and will have a discontinuity at the boundary to the confined alpha orbits.

Fig. 14 Schematic diagram of the PLT 3 MeV proton gradient detector. The detector resolves three pitch angles and therefore three slightly displaced orbits.

Fig. 15 Source-weighted minor radius of detection for the PLT 3 MeV proton gradient detector (Fig. 14) with a sample pulse height spectrum indicating the ability of the foils to displace the proton energies sufficiently to identify each pitch angle.

Fig. 16 Schematic diagram of a possible coincidence measurement on TEXT to spatially resolve the $d(^3\text{He}, p)\alpha$ fusion reaction profile. The 14.7 MeV proton detector would look for a coincident event in one of the 3.7 MeV alpha detectors. The alpha detector which had a coincident event would locate (by the intersection of the incident orbits) the position of the fusion reaction which created both particles.

Fig. 1

#86X1257

Fig. 2

Fig. 3

Fig. 4

#86X1253

Fig. 5

#86X1265

Fig. 6

#85X1258

Fig. 7

Fig. 8

Fig. 9

Fig. 10

#84X1397

Fig. 11

Fig. 12

Fig. 13

3.0 MeV proton orbits in PLT

collimator

Al foils

SB detector

Fig. 14

Fig. 15

Fig. 16

EXTERNAL DISTRIBUTION IN ADDITION TO UC-20

Plasma Res Lab, Austra Nat'l Univ, AUSTRALIA
 Dr. Frank J. Paoloni, Univ of Wollongong, AUSTRALIA
 Prof. I.R. Jones, Flinders Univ., AUSTRALIA
 Prof. M.H. Brennan, Univ Sydney, AUSTRALIA
 Prof. F. Cap, Inst Theo Phys, AUSTRIA
 M. Goossens, Astronomisch Instituut, BELGIUM
 Prof. R. Bouclicq, Laboratorium voor Natuurkunde, BELGIUM
 Dr. D. Palumbo, Dg XII Fusion Prog, BELGIUM
 Ecole Royale Militaire, Lab de Phys Plasmas, BELGIUM
 Dr. P.H. Sakanaka, Univ Estadual, BRAZIL
 Lib. & Doc. Div., Instituto de Pesquisas Especiais, BRAZIL
 Dr. C.R. James, Univ of Alberta, CANADA
 Prof. J. Teichmann, Univ of Montreal, CANADA
 Dr. H.M. Skarsgard, Univ of Saskatchewan, CANADA
 Prof. S.R. Sreenivasan, University of Calgary, CANADA
 Prof. Tudor W. Johnston, INRS-Energie, CANADA
 Dr. Hannes Barnard, Univ British Columbia, CANADA
 Dr. M.P. Bachynski, MPB Technologies, Inc., CANADA
 Chalk River, Nucl Lab, CANADA
 Zhenggu Li, SW Inst Physics, CHINA
 Library, Tsing Hua University, CHINA
 Librarian, Institute of Physics, CHINA
 Inst Plasma Phys, Academia Sinica, CHINA
 Dr. Peter Lukac, Komenského Univ, CZECHOSLOVAKIA
 The Librarian, Culham Laboratory, ENGLAND
 Prof. Schatzman, Observatoire de Nice, FRANCE
 J. Rader, CEN-BP6, FRANCE
 JET Reading Room, JET Joint Undertaking, ENGLAND
 AM Dupas Library, AM Dupas Library, FRANCE
 Dr. Tom Muel, Academy Bibliographic, HONG KONG
 Preprint Library, Cent Res Inst Phys, HUNGARY
 Dr. R.K. Chhajlani, Vikram Univ, INDIA
 Dr. B. Dasgupta, Seha Inst, INDIA
 Dr. P. Kew, Physical Research Lab, INDIA
 Dr. Philip Rosensau, 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 Clelia De Palo, Assoc EURATOM-ENEA, ITALY
 Biblioteca, del CNR EURATOM, ITALY
 Dr. H. Yamato, Toshiba Res & Dev, JAPAN
 Direc. Dept. Lg. Tokamak Dev. JAERI, JAPAN
 Prof. Nobuyuki Inoue, University of Tokyo, JAPAN
 Research Info Center, Nagoya University, JAPAN
 Prof. Kyoji Nishikawa, Univ of Hiroshima, JAPAN
 Prof. Sigeru Mori, JAERI, JAPAN
 Prof. S. Tanaka, Kyoto University, JAPAN
 Library, Kyoto University, JAPAN
 Prof. Ichiro Kawakami, Nihon Univ, JAPAN
 Prof. Satoshi Itoh, Kyushu University, JAPAN
 Dr. D.I. Choi, Adv. Inst Sci & Tech, KOREA
 Tech Info Division, KAERI, KOREA
 Bibliothek, Fom-Inst Voor Plasma, NETHERLANDS
 Prof. B.S. Lilley, University of Waikato, NEW ZEALAND
 Prof. J.A.C. Cabral, Inst Superior Tecn, PORTUGAL
 Dr. Octavian Petrus, ALI CUZA University, ROMANIA
 Prof. M.A. Hellberg, University of Natal, SO AFRICA
 Dr. Johan de Villiers, Plasma Physics, Nucor, SO AFRICA
 Fusion Div. Library, JEN, SPAIN
 Prof. Hans Wilhelmson, Chalmers Univ Tech, SWEDEN
 Dr. Lennart Stenflo, University of UMEA, SWEDEN
 Library, Royal Inst Tech, SWEDEN
 Centre de Recherches, Ecole Polytech Fed, SWITZERLAND
 Dr. V.T. Tolok, Kharkov Phys Tech Ins, USSR
 Dr. D.D. Ryutov, Siberian Acad Sci, USSR
 Dr. G.A. Eliseev, Kurchatov Institute, USSR
 Dr. V.A. Glukhikh, Inst Electro-Physical, USSR
 Institute Gen. Physics, USSR
 Prof. T.J.M. Boyd, Univ College N Wales, WALES
 Dr. K. Schindler, Ruhr Universitat, W. GERMANY
 ASDEX Reading Rm, IPP/Max-Planck-Institut für
 Plasmaphysik, F.R.G.
 Nuclear Res Estab, Jülich Ltd, W. GERMANY
 Librarian, Max-Planck Institut, W. GERMANY
 Bibliothek, Inst Plasmaforschung, W. GERMANY
 Prof. R.K. Janew, Inst Phys, YUGOSLAVIA