23-14050
PPPL-2048

UC20-A, C, F

PPPL-2048

DR-2078-08

CRODF-831011--6

INITIAL CONDITIONING OF THE TFTR VACUUM VESSEL

By

H.F. Dylla, W.R. Blanchard, R.B. Krawchuk,
R.J. Hawryluk, and D.K. Owens

JANUARY 1984

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.

PLASMA
PHYSICS
LABORATORY

MASTER

PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY

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

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

INITIAL CONDITIONING OF THE TFTR VACUUM VESSEL*

PPPL--2048

H. F. Dylla, W. R. Blanchard, R. B. Krawchuk,
R. J. Hawryluk, and D. K. Owens
Princeton Plasma Physics Laboratory,
Princeton University, Princeton, NJ 08544.

DE84 006281

ABSTRACT

We report on the initial conditioning of the Tokamak Fusion Test Reactor (TFTR) vacuum vessel prior to the initiation of first plasma discharges, and during subsequent operation with high power ohmically-heated plasmas. Following evacuation of the 86 m³ vessel with the 10⁴ l/s high vacuum pumping system, the vessel was conditioned by a 15 A dc glow discharge in H₂ at a pressure of 5 mTorr. Rapid-pulse discharge cleaning was used subsequently to preferentially condition the graphite plasma limiters. The effectiveness of the discharge cleaning was monitored by measuring the exhaust rates of the primary discharge products (CO/C₂H₄, CH₄, and H₂O). After 175 hours of glow discharge treatment, the equivalent of 50 monolayers of C and O was removed from the vessel, and the partial pressures of impurity gases were reduced to the range of 10⁻⁹-10⁻¹⁰ Torr.

Presented at the

30th National Vacuum Symposium of The American Vacuum Society

Boston, Massachusetts October 31-November 4, 1983

* This work was supported by US DOE Contract No. DE-AC02-76-CHO3073.

I. Introduction

The Tokamak Fusion Test Reactor (TFTR) began operation in December of 1982.¹ Prior to the initiation of the first plasma discharges in TFTR and during subsequent operation of the device in 1983 with high power ohmically-heated plasmas, the vacuum vessel was conditioned using various hydrogen discharge cleaning techniques. Conditioning of the first wall surfaces in tokamak vacuum vessels is essential in order to minimize plasma contamination by impurities introduced by plasma-wall interactions, such as particle and radiation-induced desorption, sputtering of surface oxides, and unipolar arcing.² Various forms of hydrogen discharge cleaning have been demonstrated to be very effective as conditioning techniques for tokamaks.³ The most commonly applied techniques are glow discharge cleaning (either dc or rf assisted), and a pulse discharge cleaning method which relies on the tokamak ohmic heating system to produce a high duty-cycle series of low current tokamak discharges. The efficiency of both types of discharge cleaning techniques is increased with simultaneous bakeout of the vacuum vessel. The end results after proper conditioning of stainless steel surfaces are substantial removal of adsorbates, significant depletion of near-surface contaminants (O, C, Cl, S, etc.) which would otherwise be accessible to discharge-induced desorption processes, and removal of arc-initiation sites.

This paper describes the combination of glow discharge and pulse discharge cleaning techniques that was employed for the initial conditioning of the TFTR vessel. The next section briefly describes the relevant specifications of the TFTR vacuum vessel, vacuum pumping system, discharge cleaning systems, and the diagnostics used to monitor the progress of discharge cleaning. The results of the discharge cleaning runs are presented in Section III, and in Section IV the results of initial vacuum vessel bakeout

tests are presented.

II. Experimental Considerations

The detailed design and construction of the TFTR vacuum vessel^{4,5} and the vacuum pumping system⁶ have been described previously in this journal; therefore, only a brief description of these systems will be given here. The vacuum vessel contains a volume of 86.5 m³ and has an approximate surface area of 200 m² exposed to vacuum. The primary structural material is 304 LN stainless steel. In addition, there are 14 large (2.9 m diameter) bellows sections in the torus fabricated from Inconel 625. Approximately 40% of the total vessel surface area and 23% of the total vessel volume are contained in two large (1 m diameter) pumping ducts which connect eight 3500 l/s turbopumps to the torus. The net high vacuum pumping speed provided by the pumps is 10,000 l/s for H₂, measured at the torus.

The important components of the TFTR glow discharge cleaning system are shown in Fig. 1. A dc glow discharge can be produced over a wide pressure range (2-200) m Torr) by biasing one or two retractable anodes located on the vessel midplane, roughly 180° apart in the toroidal direction. Separate 600 V, 20 A, current-controlled power supplies are used for biasing each anode. An active current regulation circuit and a passive arc-suppression circuit in the bias supplies eliminate the need for a large series bias resistor in the plasma circuit. The power-supplies are interlocked to thermocouple measurements of the anode temperature to shut down the system in case of excessive anode heating. Typically, both probes were operated at a current of 7.5 A each. At a hydrogen pressure of 5 mTorr, the anode voltage was 390 volts.

Pulse discharge cleaning in TFTR is accomplished by energizing the

ohmic-heating primary coils with a charging circuit which is operated at high-duty cycle in concert with the application of a steady or quasi-steady toroidal field of ~ 6 kG. The system is capable of inducing short (40-100 ms) discharges in the torus at a repetition rate of $1/6 \text{ s}^{-1}$. If the system is pulsed at a low torus pressure of $(1-2) \times 10^{-5}$ Torr, a relatively high current (100 kA), high temperature (100 eV) discharge can be produced which has been found useful for heating and conditioning the plasma-contacting (limiter) surfaces. Otherwise, the system is operated at a higher pressure of $(0.7-1) \times 10^{-4}$ Torr which results in a low current (20-40 kA), low temperature plasma (the Taylor discharge mode⁷), which is more useful for vessel wall conditioning.

The primary diagnostic instrument that was used to optimize and monitor the progress of discharge cleaning was a residual gas analyzer (RGA) appended to one of the vessel pumping ducts. Differential pumping of the RGA behind a removable aperture allows sampling of the higher pressure glow discharges in a reproducible manner. Total pressure gauging is used for measuring discharge pressures and calibrating the RGA. Magnetically-shielded ion gauges are located at two torus midplane locations, and a set of capacitance manometers is located at the end of one of the pumping ducts. In addition, ion gauges and capacitance manometers are located on each stage of the RGA to enable calibration of the system. The details of the RGA calibration procedure, which involves the use of a standard gas mixture, are given in Ref. 8. The additional calibration of the sampling aperture for the glow discharge pressure regime is described in the following section.

III. Results

The first extensive surface conditioning of the TFTR vacuum vessel was performed during a two-week period prior to the initiation of the first test plasma on December 24, 1983. Following pump-down of the vessel to $(2-3) \times 10^{-7}$ Torr and a global leak check, hydrogen GDC was applied in periods of 6-8 hrs for a total exposure of 40 hrs prior to the first attempt to produce a tokamak discharge. Then the vessel remained under vacuum for a three-week period in which there was no plasma operation, followed by another conditioning period in which an additional 40 hrs of GDC was performed. The total glow discharge current was 15 A, equally divided between the two anodes, the hydrogen pressure was (5-5.5) mTorr, and for most of the run, six of the eight vessel turbo pumps were pumping the vessel unthrottled. The vessel remained at room temperature during this (and the subsequent) GDC run because of the unavailability of the vessel bakeout system until the last month of this operation period (June 1983).

The behavior of the partial pressures of the predominant residual gases produced during this first GDC run is shown in Fig. 2. After the first few hours the impurity partial pressures exhibited a decrease that was roughly proportional to $1/t$. This power law dependence was similar to the behavior noted in the first cleaning of the PDX vacuum vessel.⁹ At the points in Fig. 2 marked with "A" and "B," the vessel was vented to atmosphere for brief periods for diagnostic adjustments. A more noticeable discontinuity in the curve is noted at point "C," which marked the three-week interruption of GDC.

After the first GDC conditioning period, approximately 200 high power tokamak discharges were performed in the vessel to test basic power and control systems. Then followed a six-week period with the vessel at atmospheric pressure for installation of internal hardware. The second GDC

conditioning run was performed during the April-June operational period. The partial pressure record of the first 100 hrs of GDC during this second conditioning period is shown in Fig. 3. The glow discharge parameters were the same as Run 1, and the GDC was applied discontinuously over a three-week period.

Comparing the partial pressures of the impurities produced in Run 2 with those produced in Run 1, the initial impurity level (i.e., at one hr) is somewhat lower in the second run, but the time dependence appears somewhat slower than $1/t$. The final pressures after ~ 100 hrs of GDC appear similar on both runs.

The partial pressure data shown in Figs. 2 and 3, which indicates impurity partial pressures produced in the TFTR vessel during GDC, are determined by measurement of the partial pressures (P_i) in the RGA scaled by the appropriate pressure reduction factor (R_i), which accounts for the conductance of the sampling aperture in the RGA, and for the differential pumping across this aperture. The values of R_i for the three gases of interest (CH_4 , H_2O , and CO) under molecular flow conditions are listed in Table 1. The use of a sampling aperture reduces the pressure from the glow discharge pressure of 5 mTorr to 2.4×10^{-4} Torr (H_2 , absolute) in the RGA chamber. However, at 5 mTorr inlet pressures, the gas flow through the aperture is somewhat viscous, thus requiring a modified value (R'_i) of the pressure reduction factor to be used. The appropriate values of R'_i are also listed in Table 1 and were determined by measuring pressure ratios of impurity gases across the aperture conductance with and without the presence of a flow of hydrogen.

The relatively high pressure of H_2 in the RGA for these measurements also causes increased background levels of the impurity gases of interest

through interactions within the ion source.¹⁰ In order to determine the net impurity production by the glow discharge, all the data points shown in Fig. 2 and 3 represent the difference between the partial pressure observed during the glow discharge and that produced by the equivalent pressure of molecular H_2 in the vessel and RGA.

The total quantity of impurities Q_i removed from the TFTR vessel during the GDC runs can be estimated by integration of the area under the pressure curves shown in Figs. 2 and 3. Since the time dependence of P_i is observed to follow a power law of the form $P_i = P_i^0(t_0/t)$, it follows that

$$Q_i = R'_i S'_i t_0 P_i^0 \int_{t_0}^t \frac{dt}{t} = R'_i S'_i t_0 P_i^0 \ln\left(\frac{t}{t_0}\right) \quad (1)$$

where S'_i is the net torus pumping speed for the species in the presence of the 5 mTorr H_2 flow; P_i^0 is the initial partial pressure of the species at time t_0 . The values of the impurity pumping speeds (S'_i) are modified from the nominal high vacuum values (S_i) for these gases, since (1) the operating pressure is above the pumping plateau for the system pumps, and (2) the presence of a background flow of H_2 affects the impurity speed. The parametric dependence of S'_i was determined by measurements of the relative pumping speeds of 1% mixtures of CH_4 , N_2 and Ar in H_2 , on a test stand, with a turbo pump similar to the TFTR pumps. The results were then scaled to the measured dependence of the pumping speed of H_2 versus pressure for the TFTR vacuum system to determine the appropriate values of S'_i listed in Table 1. Using Eq. (1) the total quantities of CH_4 , H_2O and CO molecules removed from the vessel are calculated, and these results are also listed in Table 1. The

quantities of C and O removed during Run 1 are 0.6 g and 1.2 g, respectively, and 0.3 g and 0.4 g for Run 2. Assuming a vessel surface area of $2 \cdot 10^6 \text{ cm}^2$, 40 equivalent monolayers were removed during Run 1, and 15 equivalent monolayers were removed during Run 2.

The effect of the GDC on the system base pressure is shown in Table 2, which lists the partial pressures of the primary residual gas components before and after Run 1 and Run 2. The total pressure of the impurity gases (16-44 amu) decreased from 2.9×10^{-7} Torr to 6.0×10^{-8} Torr after Run 1, and they decreased from 1.4×10^{-7} Torr to 1.5×10^{-8} Torr after Run 2. The slight increase noted in the 28 amu partial pressure after Run 2 is the result of an air leak which appeared in one of the torus bellows sections during April 1983. We infer that the CO and C_2H_4 components of the 28 amu peak were lowered significantly by the GDC, judging from large observed decreases in the C_2H_3 peak at 27 amu ($\times .04$) and the CO_2 peak at 44 amu ($\times .02$).

The GDC procedure, as performed with the vessel at room temperature, was not sufficient to condition properly the graphite limiters that were installed in the vessel during this period. These graphite limiters consisted of poloidal rings installed at two toroidal locations in the torus. They were designed conservatively in terms of dimension to provide maximum protection to vessel wall components during the TFTR start-up experiments. As a result, the quantity of graphite was relatively large (100 kg) in comparison to the active area ($\sim 10^3 \text{ cm}^2$).

An attempt to condition these limiters, along with additional wall conditioning, was made during the remainder of the April-June 1983 operations period which followed the second GDC run, by using a combination of low current and high current pulse discharge cleaning. A total of 70 hours of pulse discharge cleaning was applied during the run, with 55 hours (25,000

pulses) of high current (100-250 kA) pulse cleaning, and 15 hours (8,000 pulses) of low current (50-100 kA) pulse clearing. The residual gas production during these pulse discharge cleaning runs is summarized in Fig. 4. In general, the high current pulses were used to heat the limiters, and the CO and CH₄ production was larger than the H₂O production, increasing with limiter temperatures. The low current pulse discharge cleaning caused rapid increases in the H₂O production, which was generally larger than the CH₄ and CO production. Figure 4 shows that the total impurity production (CO + CH₄ + H₂O) during high current discharge cleaning had fallen from $\sim 3 \times 10^{-6}$ Torr on April 27 to $\sim 7 \times 10^{-7}$ Torr on May 27, just prior to switching modes to the low current pulsing. Insufficient low current pulse cleaning was performed to exhibit a decrease in impurity production with time.

Both pulse cleaning modes benefited from the vessel heating (generally in the range of 40-60°C) that resulted because of eddy currents induced by the ohmic heating circuit. These thermal excursions also had observable effects on the subsequent behavior of a GDC period which followed a pulse cleaning run: the initial impurity production during GDC would rise above the pressure curve (Fig. 3) for a period of 0.5-1 hr before returning to the curve. The exhaust rates of the pulse cleaning ($\sim 5 \times 10^{-3}$ T-l/s) compare favorably with the GDC exhaust rates near the midpoint of the GDC runs. The initial exhaust rates of the GDC are, of course, much higher ($\sim 1 \times 10^{-1}$ T-l/s).

The data of Fig. 4 indicate that more limiter conditioning was necessary, and this was born out by the evaluation of the high power discharges produced at the end of the operation period. The stability (i.e., freedom from major disruptions, and density control) of high power discharges improved markedly as a result of the pulse cleaning combined with GDC. However, the impurity content of the plasma remained relatively high, based on

estimates of Z_{eff} (3 ± 1.5) and VUV emission from oxygen ions.¹

V. Initial Bakeout Tests

It is well-established that the efficiency of hydrogen discharge cleaning schemes is greatly improved by heating the affected surfaces to moderate temperatures (100-350°C).¹¹ At the end of the described TFTR operations period, the vessel bakeout system was commissioned and tested by cycling the vessel to 100°C over a three-day period. Figure 5 shows the evolution of the vessel temperature and base pressure during the bakeout test. The relatively modest base pressure at 100°C ($\sim 5 \times 10^{-6}$ Torr) indicates that the vessel had been significantly degassed by the previous conditioning. Following return of the vessel to room temperature, the base pressure was 4×10^{-8} Torr; however, the total impurity pressure ($m > 4$ amu) was $\approx 1 \times 10^{-8}$ Torr.

V. Conclusions

Glow discharge cleaning of the TFTR vacuum vessel was effective as the first-order conditioning technique, removing more than 100 equivalent monolayers of C and O from the stainless steel and Inconel first-wall surfaces. Pulse discharge cleaning in concert with glow discharge cleaning was moderately successful in conditioning the start-up graphite limiters. More effective limiter and wall conditioning is expected in the next operational period when both discharge cleaning techniques can be applied to the vessel at elevated temperatures ($\sim 150^\circ\text{C}$).

References

1. K. M. Young et al., Proc. 11th European Conference on Controlled Fusion and Plasma Physics (Aachen, FRG 1983).
2. G. M. McCracken and P. E. Stott, Nucl. Fusion 19, 889 (1979).
3. H. F. Dylla, J. Nucl. Mater. 93 & 94, 61 (1980).
4. W. G. Reddan, J. Vac. Sci. Technol. 20, 1173 (1982).
5. D. H. Mullaney, M. A. Mozeleski, and R. B. Fleming, J. Vac. Sci. Technol. A1, 1331 (1983).
6. B. Abel, J. Vac. Sci. Technol. 15, 726 (1979).
7. L. Oren and R. J. Taylor, Nucl. Fusion 17, 1143 (1977).
8. H. F. Dylla, in Proc. IX Intern. Vacuum Congress and V Intern. Conf. on Solid Surfaces (Madrid, 1983).
9. H. F. Dylla, S. A. Cohen, S. M. Rossmagel, G. M. McCracken, and P. H. Staib, J. Vac. Sci. Technol. 17, 286 (1980).
10. H. F. Dylla and W. R. Blanchard, J. Vac. Sci. Technol. A1, 1297 (1983).
11. F. Waelbroeck, J. Winter, and P. Wienhold, KFA/Jülich (FRG) Rep. No. Jü1-pp-1692, 1980.

Table 2: Summary of TFTR base pressures before and after the two initial discharge cleaning runs and after the 100°C bakeout test.

Mass (amu)	Gas	Before GDC-1 (12-10-83) (Torr)	After GDC-1 (1-13-83) (Torr)	Before GDC-2 (3-27-83) (Torr)	After GDC-2 (5-2-83) (Torr)	After 100°C Bakeout (7-4-83)
2	H ₂	$1.7 \cdot 10^{-7}$	$4.9 \cdot 10^{-6}$	$6.1 \cdot 10^{-9}$	$3.6 \cdot 10^{-8}$	$3.0 \cdot 10^{-8}$
16	CH ₄	$1.2 \cdot 10^{-8}$	$4.0 \cdot 10^{-9}$	$1.1 \cdot 10^{-9}$	$3.3 \cdot 10^{-10}$	$1.1 \cdot 10^{-9}$
18	H ₂ O	$2.4 \cdot 10^{-7}$	$3.0 \cdot 10^{-8}$	$1.3 \cdot 10^{-7}$	$6.9 \cdot 10^{-9}$	$5.2 \cdot 10^{-9}$
28	CO/N ₂ /C ₂ H ₄	$2.5 \cdot 10^{-8}$	$2.0 \cdot 10^{-8}$	$7.2 \cdot 10^{-9}$	$7.8 \cdot 10^{-9}$	$5.6 \cdot 10^{-9}$
44	CO ₂	$1.3 \cdot 10^{-8}$	$6.0 \cdot 10^{-9}$	$9.2 \cdot 10^{-10}$	$2.0 \cdot 10^{-10}$	$3.3 \cdot 10^{-10}$
Total Impurity Pressure (16-44 amu)		$2.9 \cdot 10^{-7}$	$6.0 \cdot 10^{-8}$	$1.4 \cdot 10^{-7}$	$1.5 \cdot 10^{-8}$	$1.2 \cdot 10^{-8}$

Figures

- Fig. 1 Schematic diagram of the TFTR glow discharge cleaning system. Two glow discharge anodes are introduced into the vacuum vessel on stepping motor-driven probe mechanisms. Each probe is positively biased with separate, current-controlled, 0-20A, power supplies. The vacuum vessel is grounded to the negative side of the bias supply during glow discharge operation.
- Fig. 2 Observed decrease in the partial pressures of the predominant impurity gases produced during the first glow discharge cleaning (GDC) of the TFTR vacuum vessel performed during Dec. 82 - Jan. 1983. At positions A, B the torus was briefly vented to atmosphere, and at position C there was a three-week interruption of GDC.
- Fig. 3 Dependence of the impurity partial pressures produced during the second GDC period of Mar. - Apr. 1983. Only the initial data point is shown for H_2O (18 amu) because this signal subsequently decreased below background levels.
- Fig. 4 Time behavior of the impurity partial pressures produced during pulse discharge cleaning of TFTR over the period April - June 1983. Each point represents the maximum partial pressure produced during a typical 5-8 hr run. At approximately 55 hrs into the run the discharge cleaning technique was changed from high current to low current pulses. At 70 hrs the vessel was heated to 60°C.
- Fig. 5 Evolution of the vessel temperature and total pressure during a test of the vessel bakeout system.

TFTR GLOW DISCHARGE CLEANING SYSTEM

Fig. 2

Fig. 3

Fig. 4

Fig. 5

EXTERNAL DISTRIBUTION IN ADDITION TO TIC UC-20

Plasma Res Lab, Austr 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
 Prof. Frank Verheest, Inst theoretische, BELGIUM
 Dr. J. Palumbo, Dg XII Fusion Prog, BELGIUM
 Ecole Royale Militaire, Lab de Phys Plasmas, BELGIUM
 Dr. P.H. Sakaneke, Univ Estadual, 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. Greenlivesan, 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
 Zhengwu 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. Radet, CEN-BP6, FRANCE
 AM Dupes Library, AM Dupes Library, FRANCE
 Dr. Tom Muel, Academy Bibliographic, HONG KONG
 Preprint Library, Cent Res Inst Phys, HUNGARY
 Dr. S.K. Trehan, Panjab University, INDIA
 Dr. Indre, Mohan Lal Das, Banaras Hindu Univ, INDIA
 Dr. L.K. Chevda, South Gujarat Univ, INDIA
 Dr. R.K. Chhajlani, Var Ruchi Marg, INDIA
 P. Kow, 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 Clelia 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
 Prof. 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, Fon-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. Cabrel, Inst Superior Tech, PORTUGAL
 Dr. Octavien Petrus, ALI CUZA University, ROMANIA
 Prof. M.A. Hallberg, University of Natal, SO AFRICA
 Dr. Johan de Villiers, Atomic Energy Bd, 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
 Dr. Erik T. Karlson, Uppsala Universitet, SWEDEN
 Centre de Recherches, Ecole Polytech Fed, SWITZERLAND
 Dr. W.L. Weise, Nat'l Bur Stand, USA
 Dr. H.M. Stacey, Georg Inst Tech, USA
 Dr. S.T. Wu, Univ Alabama, USA
 Prof. Norman L. Oleson, Univ S Florida, USA
 Dr. Benjamin Ma, Iowa State Univ, USA
 Prof. Magne Kristiansen, Texas Tech Univ, USA
 Dr. Raymond Askew, Auburn Univ, USA
 Dr. V.T. Toich, 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. Boyd, Univ College N Wales, WALES
 Dr. K. Schindler, Ruhr Universität, 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 Plasmatechnik, W. GERMANY