IMPLICATIONS OF POLARIZED DT PLASMAS
FOR TOROIDAL FUSION REACTORS

by

B. J. Micklich and D. L. Jassby

Plasma Physics Laboratory, Princeton University
Princeton, NJ 08544

ABSTRACT

Spin polarization of the deuterons and tritons in a reacting plasma can result in an increase in the fusion reactivity and variation of the angular distribution of emission of the fusion neutrons. The increased fusion reactivity relaxes the confinement-temperature conditions for breakeven and ignition. We have determined the effect of varying the angular distribution of the fusion neutrons on the spatial distribution of fusion neutron current and flux at the first wall, on the global tritium breeding ratio, and on the first-wall radiation damage in low-aspect-ratio toroidal geometry.

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.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *Ree*

I. INTRODUCTION

Recent analyses have shown the feasibility of operating a magnetic confinement fusion device with polarized reactants, as the calculated depolarization times are much longer than the total lifetime of a reacting nuclide in the reactor.¹ This study presents modified ignition and break-even curves for plasmas with polarized reactants, calculates the uncollided fusion neutron current and scalar flux at the first wall of a tokamak for several polarization cases of interest, and examines the consequences for global tritium breeding and first-wall radiation damage.

Nearly all DT reactions (at least 95%) proceed through a resonant $3/2^+$ state of the ^5He compound nucleus.² This state is only 107 keV above the energy of the free deuterium and tritium nuclei which combine to form it, which accounts for the magnitude of the reaction cross section at low energies. The spin of the compound nucleus and reaction products, along with the parity of the compound nucleus, dictates that the wave function describing the products be constructed from eigenfunctions with angular momentum quantum number (l) equal to 2. A simple application of quantum mechanics gives¹

$$\sigma = (a + \frac{2}{3} f + \frac{1}{3} c) f \sigma_0 + (\frac{2}{3} b + \frac{4}{3} c) (1-f) \sigma_0$$

for the total reaction cross section, and

$$\frac{\partial \sigma}{\partial \Omega} = \frac{f \sigma_0}{2\pi} [\frac{3}{4} a \sin^2 \theta + (\frac{2}{3} b + \frac{1}{3} c) (\frac{4/f - 3 + 3 \cos^2 \theta}{4})]$$

for the differential cross section, which describes the angular distribution of the reaction products. In these equations $a \equiv d_{+t_+} + d_{-t_-}$, $b \equiv d_0$, $c \equiv d_{+t_-} + d_{-t_+}$ (where plus, zero, and minus subscripts refer to polarization parallel, perpendicular, and antiparallel to $\vec{B}$), θ is the polar angle of emission measured with respect to the local magnetic field direction, and σ_0 is the reaction cross section when the D and T have spins parallel.

When there is no polarization of the reactants (referred to here as an iso-DT plasma), the angular distribution of reaction products is isotropic. If the deuterons are polarized perpendicular to $\vec{B}$, and the tritons have no polarization, the angular distribution of reaction products is proportional to $1+3\cos^2\theta$. This case, which offers no reactivity enhancement over iso-DT, is called transverse-D. A third case, where both the deuterons and tritons are polarized along $\vec{B}$, is called ortho-DT, by analogy to the ortho-hydrogen molecule in which the spins of the two protons are parallel. Here, the angular distribution of reaction products is proportional to $\sin^2\theta$; most importantly, this case also offers a 50% increase in fusion reactivity. The characteristics of these three cases are summarized in Table I.

II. MODIFICATION OF $n\tau_E$ REQUIREMENTS

The confinement-temperature conditions for thermonuclear ignition and for energy "breakeven" are relaxed when the reactants are at least partially polarized in the ortho-DT mode. (Here "breakeven" is defined as the conditions where the fusion power equals the external heating power required to maintain the plasma temperature against all transport and radiation losses. "Ignition" is defined as the conditions where the fusion alpha power maintains the plasma temperature against all transport and radiation losses.) Figure 1 shows how the $n\tau_E$ conditions are modified³ for the case of an ortho-DT plasma which has the maximum cross-sectional enhancement of 50%. All curves are for plasmas with $T_e = T_i$ and $Z_{eff} = 1$. The fusion cross sections were taken from Ref. 1.

At large T_i the $n\tau_E$ requirement for breakeven or ignition is reduced by a factor of 1.5 from that in the unpolarized plasma. At lower temperatures where bremsstrahlung radiation becomes significant, polarization of the reactants results in a more significant reduction in the required $n\tau_E$. The minimum temperature required for ignition or for breakeven is also reduced when the ortho-DT plasma is used.

III. SPATIAL CURRENT AND FLUX DISTRIBUTIONS

Figure 2 shows the model used in calculating the current and scalar flux at the first wall. A toroidally symmetric plasma vessel with rectangular cross-sectional area is employed, characterized by major radius R_v , minor radius a_v , and a vertical elongation of b_v/a_v . The neutron source is a ring located at $R=R_v$, $z=0$.

The expressions for the normal component of uncollided neutron current,

$$J_n = \int \frac{\hat{n} \cdot \hat{r}}{r^3} f_n(\theta) d\phi \quad (1)$$

and the uncollided scalar flux,

$$\phi = \int \frac{f_n(\theta)}{r^2} d\phi \quad (2)$$

at the first wall are integrated over all source points that have a direct line of sight to the position on the wall being considered. An analytic expression can be obtained for the flux, while the integral for the current must be evaluated numerically. The expressions for f_n have been normalized to a total source strength of 2π .

The radial profile of the fusion neutron source is generally unimportant for determining wall loading distributions. Table II shows a comparison of some results from this study with results from Ref. 5, in which a vacuum vessel of circular cross section with $R_v = 10.0$ m and $a_v = 3.67$ m was used with a ray-tracing

technique to determine angular fluxes and currents at the first wall. In comparing the variation of scalar flux and current between inboard and outboard positions in the toroidal midplane, one sees that the results of the simple treatment used in this study are in good agreement with a more detailed analysis. The outward shift of the neutron source from R_v in the case of a high pressure plasma would raise the current and flux at the outboard wall and lower them at the inboard wall.⁵ This effect is neglected in the present study.

Figure 3 shows the calculated distribution of uncollided fusion neutron current along the first wall for the three polarization cases. The results shown are for a vacuum vessel aspect ratio of 3.2 and vertical elongation of 2.0, which are typical values for compact DT reactors. The iso-DT case [dashed lines in Figs. 3(a) and 3(b)] exhibits a higher current at the outboard wall than inboard. This difference is enhanced significantly in the transverse-D case, due to directionality of $f_n(\theta)$ along $\vec{B}$, at all vertical positions $|z|/a_v$. The ratio J_n^{out}/J_n^{in} at the midplane increases from 1.13 for iso-DT to 1.90 for transverse-D, and becomes greater with increasing $|z|/a_v$. The ortho-DT case, with strong directionality perpendicular to $\vec{B}$, produces an inboard current greater than the outboard current for wall positions $|z|/a_v < 1.25$.

The fractions of fusion neutron production directed to various parts of the vacuum vessel are given in Table III. These results show that the various source angular distributions can be used to effect significant changes in the spatial distribution of

neutrons. For example, with transverse-D polarization one can direct 62% of the fusion neutrons to outboard regions with just 14% directed toward the inboard, while ortho-DT polarization can result in just 42% of the neutrons going to the outboard with 27% and 31% going to the inboard and to the top and bottom, respectively.

Figure 4 shows the scalar flux at the first wall due to uncollided fusion neutrons. While the difference between outboard and inboard fluxes is relatively small (<20%) for iso-DT, the outboard wall flux is much greater than the inboard for transverse-D, with the reverse being true for ortho-DT. Little variation exists in scalar flux along the top or bottom, except for $R/R_v < 1$.

IV. GLOBAL TRITIUM BREEDING RATIO

The one-dimensional neutron transport code ANISN⁶ was used to investigate the response of toroidal fusion systems to changes in the neutron source angular distribution $f_n(\theta)$. The model used in these calculations is shown in Fig. 5. The region inboard of the plasma is made non-breeding: its composition is a 20-cm layer of a neutron multiplying material backed by a 40-cm reflector of SS 316. Tritium breeding is done exclusively on the outboard side in a blanket consisting of a homogeneous mixture of 80% natural lithium and 20% beryllium, which is followed by a 20-cm thick reflector of stainless steel. The neutron source is a plane located at $R = 400$ cm. Calculations were carried out in P_3 - S_{12} approximation with a 25 n, 12 γ group cross section set

collapsed from the 171 n, 36 γ group DLC41/C library.⁷

Tritium breeding ratios with non-breeding inboard regions were reported in Ref. 8, which used a model similar to that in Fig. 5. With the tritium breeding ratio (TBR) defined as tritons produced per fusion neutron, it was shown that a TBR of at least 1.7 could be achieved in idealized systems (no structure, coolant, or penetrations) by optimizing the inboard region for reflection of neutrons. Lead (backed by Zircaloy) was found to be the best inboard reflector. The present study also considers stainless steel, because of its presence as a structural material in many reactor design concepts, and graphite, because of its wide use as a neutron reflector.

Table IV shows the variation in TBR for the lead, stainless steel, and graphite inboard reflectors as a function of the source angular distribution. When the inboard region is optimized for neutron reflection, the TBR is only weakly dependent on the source angular distribution. The lead reflector shows only a $\pm 2.5\%$ variation from the iso-DT case when the transverse-D or ortho-DT plasma is used. The variation in TBR is only $\pm 5\%$ when stainless steel is used, and approximately $\pm 6\%$ for graphite, though the absolute values of TBR are somewhat lower than with lead. One can thus take advantage of the 50% enhancement in fusion reactivity available with the ortho-DT polarization without sacrificing significant potential for tritium breeding. The $\sin^2\theta$ angular distribution of the ortho-DT case is also more suitable for extraction of collimated beams of fusion neutrons.⁹

V. FIRST-WALL RADIATION DAMAGE

The same ANISN calculations described in Section IV were used to obtain estimates of first-wall damage for the three polarization cases. The three quantities investigated were displacements per atom (normalized to 1 MW-yr/m^2) and total hydrogen and helium gas production (each normalized to 1 source neutron/s). The results are shown in Table V, for the case of the lead neutron multiplier inboard. (Similar results are obtained in the stainless steel case.)

For all three damage estimates, the damage rates in the outboard wall are nearly independent of the source angular distribution. This result is due to the fact that large numbers of energetic neutrons are reflected from the inboard region, for any polarization of the plasma. For example, the dominant contribution to displacement damage comes from neutrons in the source energy group. In this group the scalar flux in the outboard first wall is only 4 % greater for transverse-D than for ortho-DT. Lower energy groups (2.5-12 MeV) show similar or somewhat greater percentage differences in flux, but at absolute magnitudes a factor of 10 lower than the total flux in the source group. Groups with energy below 2.5 MeV show greater flux for ortho-DT than transverse-D, and at somewhat higher absolute values than for energies $2.5 \text{ MeV} < E < 12 \text{ MeV}$ (though the displacement cross section here is lower). Thus the reduced damage for ortho-DT due to neutrons in the energy range 2.5-12 MeV is cancelled by increased damage due to neutrons with $E < 2.5$

MeV, keeping the damage for all polarization cases nearly constant.

The inboard wall, on the other hand, shows a decrease in damage of 20-30% for the transverse-D case from iso-DT, and a 20-30% increase for ortho-DT over iso-DT. In this latter instance, the inboard first wall damage rates are as great or greater than those at the outboard first wall. These increased damage rates are due to the greater numbers of fusion neutrons emitted toward the inboard region. Therefore, the increased reactivity of the ortho-DT case carries the price of much higher damage rates, which translates directly into shorter component lifetimes, in the inboard regions where access and maintenance are difficult.

VI. CONCLUSIONS

Operation of a toroidal magnetic confinement fusion device with polarized reactants can offer several new performance modes. Use of the different polarization states considered here allows variation of the spatial distribution of fusion neutrons between inboard, outboard, and top and bottom regions. Even if no tritium breeding is done in the region inboard of the plasma, the global tritium breeding ratio can be made insensitive to the polarization state of the plasma by optimizing the inboard region for neutron reflection. Then the ortho-DT polarization may be used for reactivity enhancement or extraction of neutron beams without sacrificing significant tritium breeding potential, in the limiting case of only small-diameter penetrations of the breeding blankets.

Outboard first-wall damage estimates are insensitive to the polarization of the plasma, while damage estimates for the inboard first wall show considerable variation with polarization (i.e., source angular distribution). In particular, use of the ortho-DT polarization leads to damage rates per source neutron that are 20-30% higher than with no polarization.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy Contract No. DE-AC02-76-CHO-3073. B. J. Micklich was supported by a Fannie and John Hertz Foundation Fellowship. The authors acknowledge useful discussions with R. Kulsrud, E. Valeo, R. Budny, L. P. Ku, and J. Kolibal.

REFERENCES

- ¹R. M. Kulsrud, H. P. Furth, E. J. Valeo and M. Goldhaber, "Fusion Reactor Plasmas with Polarized Nuclei," Phys. Rev. Lett. 49, 1248-51 (1982).
- ²J. P. Connor, T. W. Bonner, and J. R. Smith, Phys. Rev. 88, 468 (1952).
- ³D. L. Jassby, "Break-even and Ignition Conditions for Polarized Fusion Plasmas," Princeton Plasma Physics Laboratory Report (to be published).
- ⁴G. H. Miley, H. H. Towner, and N. Ivich, "Fusion Cross Sections and Reactivities," University of Illinois Nuclear Engineering Department Report No. COO-2218-17, 1974.
- ⁵D. L. Chapin and W. G. Price, "Neutron Wall Load Distributions in Tokamaks," Nucl. Technology 31, 32-47 (1976).
- ⁶"ANISN-PPL: Multigroup One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering and Provision for Binary Output," CCC-253, RSIC, Oak Ridge National Laboratory Report No. CCC-253, RSIC, 1975; modified by L. P. Ku and J. Kolibal for use on Cray-1 computers (1982).
- ⁷L. P. Ku, "Nuclear Radiation Analysis for TFTR," Princeton Plasma Physics Laboratory Report PPPL-1711, 1980.
- ⁸B. J. Micklich, D. L. Jassby, and C. E. Clifford, "Maximum Tritium Production in Toroidal Fusion Reactors with No Inboard Breeding," Trans. Am. Nucl. Soc. 41, 172-173 (1982).

9

D. L. Jassby, "Potential of the TFTR as a Fusion Neutron Test Facility," in: Proceedings of the Conference on Fast, Thermal, and Fusion Reactor Experiments, Salt Lake City, UT, 1982 (American Nuclear Society, Salt Lake City, 1982) Vol. II, pp. 293-304.

Table I

PRINCIPAL POLARIZATION OPTIONS FOR DT PLASMAS

	Iso-DT	Transverse-D	Ortho-DT
Polarization	None	$D \perp \vec{B}$ T arbitrary	$D, T \parallel \vec{B}$
Reactivity Enhancement	None	None	50%
Angular Distribut. Fusion Neutrons $f_n(\theta)$	Isotropic	$1 + 3 \cos^2 \theta$	$\sin^2 \theta$

Table II

EFFECT OF SOURCE PROFILE ON
NEUTRON WALL LOADING VARIATION

SOURCE ^a	$J_n^{\text{out}}/J_n^{\text{in}}$	$\phi_{\text{in}}/\phi_{\text{out}}$
Ring	1.12	1.10
Uniform ^b	1.18	1.08
Peaked ^b	1.16	1.10

^aIsotropic source angular distribution

^bD. L. Chapin & W. G. Price, Nucl. Technology 31, 32-47 (1976).

Micklich & Jassby

Table III

EFFECT OF REACTANT POLARIZATION ON
SPATIAL DISTRIBUTION OF UNCOLLIDED CURRENT

Polariza- tion of Reactants	Source Angular Distribut.	Fraction of Neutrons to Outboard	Fract. of Neutr. to Inboard	Fract. of Neutr. to Top & Bottom
None	$1/4\pi$	0.523	0.203	0.27 ^a
D Polarized Transverse to B	$\frac{1 + 3\cos^2\theta}{8\pi}$	0.621	0.140	0.239
D and T Polarized Along B	$\frac{3\sin^2\theta}{8\pi}$	0.422	0.268	0.310

Micklich & Jassby

Table IV
EFFECT OF REACTANT POLARIZATION ON
GLOBAL TRITIUM BREEDING RATIO

Polariza- tion of Reactants	Source Angular Distribut.	TBR from 1-D Toroidal Model ^a		
		Inboard Material		
		S. Steel ^b	Lead ^c	Graphite
None	$1/4\pi$	1.39	1.54	1.37
D Polarized Transverse to B	$\frac{1 + 3\cos^2\theta}{8\pi}$	1.46	1.59	1.46
D and T Polarized Along B	$\frac{3\sin^2\theta}{8\pi}$	1.32	1.50	1.29

^aOutboard blanket composition: 1 cm SS316 wall, 60 cm (80% Li & 20% Be), and 20 cm SS316 reflector

Inboard blanket composition: 1 cm SS316 wall, 20 cm SS316 or Pb, and 40 cm SS316 reflector

^bRef. 7, Case #14

^cRef. 7, Case #12

Table V

RADIATION DAMAGE TO FIRST WALL

Pb inboard neutron multiplier

Source Angular Distribution	dpa/(MW-yr/m ²)		H Gas Production* (10 ⁻⁶ atoms/cm ³ s)		He Gas Production* (10 ⁻⁶ atoms/cm ³ s)	
	inboard	outboard	inboard	outboard	inboard	outboard
Isotropic	12.58	14.61	5.69	7.44	1.51	1.97
$\frac{1}{8\pi} (1+3\cos^2\theta)$	9.97	14.76	4.12	7.62	1.07	2.02
$\frac{3}{8\pi} \sin^2\theta$	15.19	14.45	7.26	7.25	2.01	1.94

*Normalized to 1 neutron per second

Micklich & Jassby

FIGURE CAPTIONS

- FIG. 1 Ignition and energy break-even conditions.
- FIG. 2 Model of tokamak geometry used in calculation of uncollided current and scalar flux at first wall.
- FIG. 3 Spatial distributions of uncollided neutron current for source angular distributions corresponding to various polarizations of D and T. Neutron current has units of neutrons/m²/s if R_v is measured in meters.
- FIG. 4 Spatial distribution of uncollided neutron scalar flux for source angular distributions corresponding to various polarizations of D and T. Scalar flux has units of neutrons/m²/s if R_v is measured in meters.
- FIG. 5 One-dimensional toroidal cylinder model used in ANISM calculations of tritium breeding and first-wall radiation damage.

Figure 1. Ignition and energy break-even conditions.

Figure 2. Model of tokamak geometry used in calculation of uncollided current and scalar flux at the first wall.

Figure 3. Spatial distributions of uncollided neutron current for source angular distributions corresponding to various polarizations of D and T. Neutron current has units of neutrons/m²/s if R_v is measured in meters.

#82P0329

Figure 4. Spatial distribution of uncollided neutron scalar flux for source angular distributions corresponding to various polarizations of D and T. Scalar flux has units of neutrons/m²/s if R_v is measured in meters.

Figure 5. One-dimensional toroidal cylinder model used in ANISN calculations of tritium breeding and first-wall radiation damage.

EXTERNAL DISTRIBUTION IN ADDITION TO TIC UC-20

Plasma Res Lab, Austro Nat'l Univ, AUSTRALIA
 Dr. Frank J. Pecloni, Univ of Wollongong, AUSTRALIA
 Prof. J.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. D. Palumbo, Dg XII Fusion Prog, BELGIUM
 Ecole Royale Militaire, Lab de Phys Plasmas, BELGIUM
 Dr. P.H. Sakemaka, Univ Estadual, BRAZIL
 Dr. C.R. James, Univ of Alberta, CANADA
 Prof. J. Teichmann, Univ of Montreal, CANADA
 Dr. H.M. Skarsoerd, Univ of Saskatchewan, CANADA
 Prof. S.R. Greenlason, University of Calgary, CANADA
 Prof. Tudor W. Johnston, INRS-Energie, CANADA
 Dr. Hannas Barnard, Univ British Columbia, CANADA
 Dr. W.P. Bochnski, MPB Technologies, Inc., CANADA
 Zhongwu Li, SW Inst Physics, CHINA
 Library, Tsing Hua University, CHINA
 Librarian, Institute of Physics, CHINA
 Inst Plasma Phys, SW Inst Physics, CHINA
 Dr. Peter Lukac, Komenského Univ, CZECHOSLOVAKIA
 The Librarian, Culham Laboratory, ENGLAND
 Prof. Schatzman, Observatoire de Nice, FRANCE
 J. Radet, CEN-BP6, FRANCE
 AM Dupas Library, AM Dupas Library, FRANCE
 Dr. Tom Muai, Academy Bibliographic, HONG KONG
 Preprint Library, Cent Res Inst Phys, HUNGARY
 Dr. A.K. Sundaram, Physical Research Lab, INDIA
 Dr. S.K. Trehan, Punjab University, INDIA
 Dr. Indra, Mohan Lal Das, Banaras Hindu Univ, INDIA
 Dr. L.K. Chavda, South Gujarat Univ, INDIA
 Dr. R.K. Chhajlani, Var Ruchi Marg, INDIA
 P. Kaw, 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, Inst Ctr Theo Phys, ITALY
 Miss Cielia 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. Setoshi 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. Cabral, Inst Superior Tech, PORTUGAL
 Dr. Octavian Petru, ALI CUZA University, ROMANIA
 Dr. R. Jones, Nat'l Univ Singapore, SINGAPORE
 Prof. M.A. Heilberg, University of Natal, SO AFRICA
 Dr. Johan de Villiers, Atomic Energy Bd, SO AFRICA
 Dr. J.A. Togle, 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. Wales, Nat'l Bur Stand, USA
 Dr. W.M. Stacey, Georg Inst Tech, USA
 Dr. S.T. Wu, Univ Alabama, USA
 Prof. Norman L. Olsson, Univ S Florida, USA
 Dr. Benjamin Ma, Iowa State Univ, USA
 Prof. Magna Kristiansen, Texas Tech Univ, USA
 Dr. Raymond Askew, Auburn Univ, USA
 Dr. V.T. Tolok, Kharkov Phys Tech Ins, USSR
 Dr. D.D. Ryutov, Siberian Acad Sci, USSR
 Dr. M.S. Rabinovich, Lebedev Physical Inst, USSR
 Dr. G.A. Eliseev, Kurchatov Institute, USSR
 Dr. V.A. Glukhikh, Inst Electro-Physiol, USSR
 Prof. T.J. Boyd, Univ College N Wales, WALES
 Dr. K. Schindler, Ruhr Universitet, W. GERMANY
 Nuclear Res Estab, Julich Ltd, W. GERMANY
 Librarian, Max-Planck Institut, W. GERMANY
 Dr. H.J. Kneppeler, University Stuttgart, W. GERMANY
 Bibliothek, Inst Plasmaforschung, W. GERMANY