40/8-15-95 JS (2)

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

PPPL-3116
UC-420

PPPL-3116

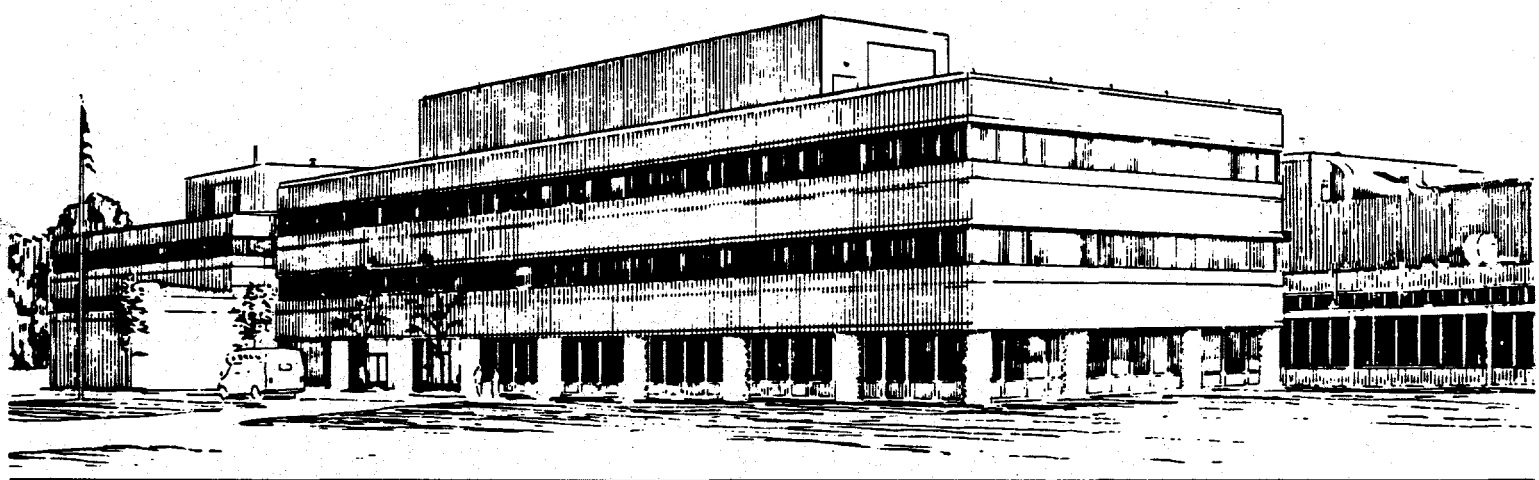
ENHANCED LOSS OF FUSION PRODUCTS DURING MODE CONVERSION HEATING IN TFTR

BY

D.S. DARROW, R. MAJESKI, N.J. FISCH, ET AL.

JULY 1995

PPPL PRINCETON PLASMA PHYSICS LABORATORY



PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY

NOTICE

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 produce, 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.

NOTICE

This report has been reproduced from the best available copy.
Available in paper copy and microfiche.

Number of pages in this report: 7

DOE and DOE contractors can obtain copies of this report from:

Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831;
(615) 576-8401.

This report is publicly available from the:

National Technical Information Service
Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
(703) 487-4650

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Enhanced Loss of Fusion Products During Mode Conversion Heating in TFTR

D. S. Darrow, R. Majeski, N. J. Fisch, R. F. Heeter,
H. W. Herrmann, M. C. Herrmann, M. C. Zarnstorff,
and S. J. Zweben

Princeton University, Plasma Physics Laboratory,
PO Box 451, Princeton, New Jersey 08543-0451, USA

ABSTRACT

Ion Bernstein waves (IBWs) have been generated by mode conversion of ion cyclotron range of frequency (ICRF) fast waves in TFTR. The loss rate of fusion products in these discharges can be large, up to 10 times the first orbit loss rate. The losses are observed at the passing/trapped boundary, indicating that passing particles are being moved onto loss orbits either by increase of their $v_\perp$ due to the wave, by outward transport in minor radius, or both. The lost particles appear to be DD fusion produced tritons heated to ~1.5 times their birth energy.

INTRODUCTION

IBWs have been produced in TFTR by mode conversion of ICRF fast waves in plasmas with large fractions of ^{3}He, for the purposes of electron heating and current drive.[1] The mode conversion occurs at the two-ion hybrid layer, and the resulting IBW is absorbed by electrons within a few cm of the mode conversion layer. The major radius of the mode conversion layer can be controlled by varying the toroidal field strength and the fractional abundance of ^{3}He (the remainder of the plasma being principally D and ^{4}He). Typical discharge conditions are: R=2.625 m, a=0.99 m, B_T=4.8 T, I_p=1.4 MA, $n_e(0)=5\times10^{19}$ m^{-3}, $n_{3He}/n_e \geq 0.1$, $T_e(0)$=7 keV, P_{NB}=0–10 MW, and P_{RF}=3–5 MW (43 MHz). Under some conditions, enhanced losses of charged fusion products (CFPs) are seen at the wall during these experiments. The CFP loss rate is measured by detectors at 90°, 60°, 45°, and 20° below the outer midplane, at a single toroidal location.[2] Each detector measures the total flux and the gyroradius and pitch angle distributions as functions of time. They are, however, unable to discriminate between ions of different charge or mass if they possess the same gyroradius.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

CHARACTERISTICS OF THE LOSS

Figure 1 compares the time histories of two similar IBW discharges. The only difference between them is in the fraction of ^{3}He present. The solid line shows data from a discharge with 67% ^{3}He in the gas puffed into the vessel, while the broken line is for one with 50% ^{3}He. The total CFP loss rate for the discharge with 67% ^{3}He puffing exceeds that in the other on all detectors by up to a factor of ten. The losses in the comparison shot are about at the level of first orbit loss, ~10% of the CFP birth rate.[3] The variation of the losses appears to be correlated with small changes in the edge density, and may relate to the coupling or propagation of waves in the edge. Another comparison shot, like those shown but with no NBI, has no detectable losses. This indicates that the losses are indeed fusion products, since these detectors are insensitive to beam ions and there is no rf-produced energetic tail. From Fig. 1, it is clear that the loss rate can transiently be a substantial fraction of the source rate. Such large losses in a reactor might damage the first wall.

Figure 2 compares the pitch angle distribution of the loss to the 90° detector during IBWH with a normal first orbit loss distribution. The loss during IBWH is centered at the pitch angle of the passing/trapped boundary for this detector, and the width of the distribution is equal to the instrumental width. Loss at the passing/trapped boundary would be seen if the CFPs are being transported outward in minor radius[4] or if they are being given additional $v_\perp$ by the IBW.[5]

Figure 3 compares the gyroradius distribution of the loss in the 90° detector during IBWH to first orbit loss. The first orbit loss distribution shows the effect of instrumental broadening, since it consists of only birth-energy particles. The distribution during IBWH peaks at a higher gyroradius and has a larger FWHM than does the first orbit loss distribution. Both indicate that escaping particles have been significantly heated. The observed gyroradius distribution matches that of CFPs at 50% above their birth energy.

SPECIES INVOLVED

The losses described above have been seen in plasmas which are principally composed of ^{3}He, ^{4}He, and D, with D neutral beams. Hence, there will be both DD and D^{3}He fusion products present which may be lost. However, some features of the detector system allow the range of species involved to be narrowed.

The D^{3}He fusion products are a 14.7 MeV proton and a 3.7 MeV alpha particle. The DD CFPs are a 3 MeV proton, 1 MeV triton, and 800 keV ^{3}He ion. Of these, the 14.7 MeV proton can be eliminated since its gyroradius does not match that seen, and it contributes negligibly to the total signal. The 800 keV ^{3}He ion cannot enter the detectors unless it is heated to ≥900 keV, and even then its gyroradius does not match the observations. Hence, it can be omitted from consideration. The remaining particles, the 3.7 MeV alpha, the 3 MeV proton, and the 1 MeV triton, cannot be excluded based upon detectability. All have similar gyroradii as well.

If the D beams are replaced with T beams, the IBW-related loss appears to vanish. Two possibilities might explain this change: (1) the loss has, in fact, stopped; or (2) the loss is still present, but is overwhelmed by the loss of DT alpha particles. This, we suggest, makes it unlikely that the observed losses are due to the 3.7 MeV D^3He alpha particle. T beam injection produces alpha particles at 3.5 MeV, an energy only 6% different from the D^3He alphas. Since the process involved increases the lost particles' energies by ~50%, we expect the loss process to work equally well with DT alphas as with D^3He alphas. Yet, with a substantially larger source of alphas, the loss does not grow but remains the same or vanishes. Hence, we conjecture that the IBW-related losses are not of alpha particles.

This leaves the DD CFPs, 3 MeV protons and 1 MeV tritons, as possibilities. Of these two, the plasma conditions are such that there will be a $2\Omega_T$ resonance at R=3.00 m, while there will be no proton cyclotron resonance in the plasma at all, favoring the hypothesis that the losses are of energetic tritons.

POTENTIAL FOR CONTROL OF α PARAMETERS

The above results indicate that there is a strong interaction between the IBW and CFPs under appropriate conditions. This interaction might have use in ash removal, burn control, current drive, and transfer of the alpha particle energy to plasma ions.[6] In this last case, the object would be to improve the reactivity of a plasma by direct transfer of alpha energy to the ions, while at the same time transporting the alphas toward the plasma edge where they would eventually be pumped out. Considerable further experimentation, analysis, and modeling will be required before the intriguing results reported here can be applied to practical needs.

ACKNOWLEDGEMENT

This work was supported by US DoE contract DE-AC02-76-CHO-3073.

REFERENCES

[1]R. Majeski, et al., these proceedings.
[2]D. S. Darrow, H. W. Herrmann, D. W. Johnson, R. J. Marsala, R. W. Palladino, and S. J. Zweben, *Rev. Sci. Instrum.* **66**, 476 (1995).
[3]R. Boivin, S. J. Zweben, and R. B. White, *Nucl. Fusion* 33, 449 (1993).
[4]Liu Chen, J. Vaclavik, and G. W. Hammett, *Nucl. Fusion* **28**, 389 (1988).
[5]C. S. Chang, *Phys. Fluids* **28**, 3598 (1985).
[6]N. J. Fisch and J.-M. Rax, *Phys. Rev. Lett.* **69**, 612 (1992).

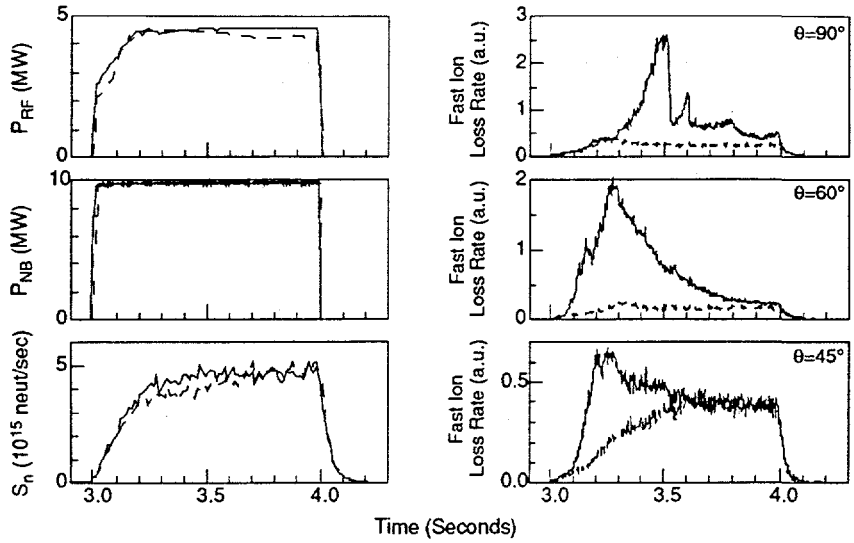


FIGURE 1. ICRF power, neutral beam power, neutron rate, and fast ion loss rate to detectors 90°, 60°, and 45° below the outer midplane for two similar discharges in TFTR. The shot plotted with the dashed line (81548) had 50% ^{3}He in its gas fueling, while the shot plotted with the solid line (81547) had 67% ^{3}He gas fueling.

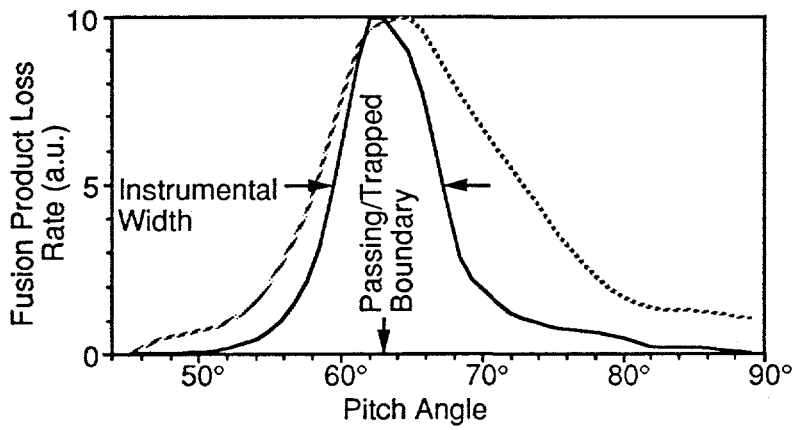


FIGURE 2. Pitch angle distributions of the IBW-related loss (solid line) and first orbit loss (dashed line) in the 90° fast ion detector. The IBW loss is centered at thepitch angle of the passing/trapped boundary, and its width is due to instrumental broadening. The IBW loss has been normalized to the amplitude of the first orbit loss in this figure.

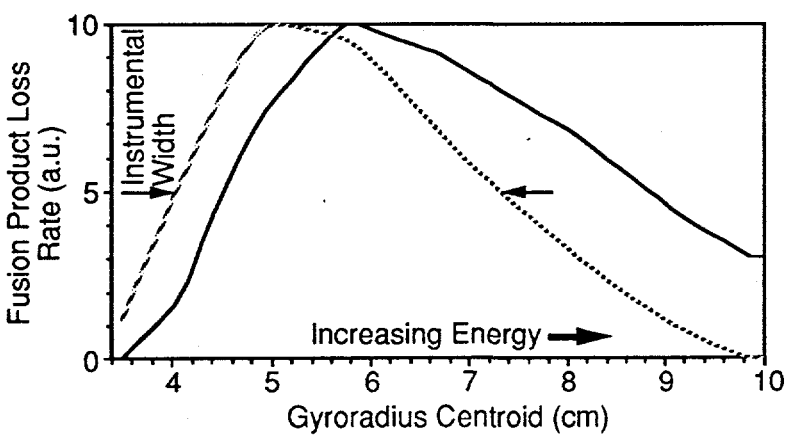


FIGURE 3. Gyroradius distributions of the IBW-related loss (solid line) and first orbit loss (dashed line) in the 90° detector. The width of the first orbit loss distribution is due to instrumental broadening, and its peak is at the gyroradius corresponding to birth-energy charged fusion products. The IBW loss case peaks at a higher gyroradius and is broader, both indicating significant heating of the fusion products before their loss.

EXTERNAL DISTRIBUTION IN ADDITION TO UC-420

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