

Joint Varenna-Grenoble International Symposium

HEATING IN TOROIDAL PLASMAS

Volume 1

Published for the
COMMISSION OF THE EUROPEAN COMMUNITIES
by
PERGAMON PRESS

HEATING IN TOROIDAL PLASMAS

Volume 1

Also published by Pergamon Press for the Commission of the European Communities in this series

Pulsed Fusion Reactors
Course on Plasma Diagnostics and Data Acquisition Systems
Proceedings of the 9th Symposium on Fusion Technology
Third Symposium on Plasma Heating in Toroidal Devices
Plasma Wall Interaction
Tokamak Reactors for Breakeven
Theory of Magnetically Confined Plasmas
Plasma Transport, Heating and MHD Theory
Fusion Technology 1978
Diagnostics for Fusion Experiments
Driven Magnetic Fusion Reactors

NOTICE TO READERS

Dear Reader

If your library is not already a standing order customer or subscriber to this series, may we recommend that you place a standing or subscription order to receive immediately upon publication all new volumes published in this valuable series. Should you find that these volumes no longer serve your needs your order can be cancelled at any time without notice.

ROBERT MAXWELL
Publisher at Pergamon Press

Joint Varenna-Grenoble International Symposium

HEATING IN TOROIDAL PLASMAS

Proceedings of the Symposium held at the Centre d'Etudes Nucléaires,
Grenoble, France, 3-7 July 1978

In Two Volumes

Edited by

T. Consoli

*Association Euratom-CEA, Centre d'Etudes Nucléaires,
Grenoble, France*

Volume 1

Published for the
COMMISSION OF THE EUROPEAN COMMUNITIES
by
PERGAMON PRESS

OXFORD · NEW YORK · TORONTO · SYDNEY · PARIS · FRANKFURT

U.K.	Pergamon Press Ltd., Headington Hill Hall, Oxford OX3 0BW, England
U.S.A.	Pergamon Press Inc., Maxwell House, Fairview Park, Elmsford, New York 10523, U.S.A.
CANADA	Pergamon of Canada, Suite 104, 150 Consumers Road, Willowdale, Ontario M2J 1P9, Canada
AUSTRALIA	Pergamon Press (Aust.) Pty. Ltd., P.O. Box 544, Potts Point, N.S.W. 2011, Australia
FRANCE	Pergamon Press SARL, 24 rue des Ecoles, 75240 Paris, Cedex 05, France
FEDERAL REPUBLIC OF GERMANY	Pergamon Press GmbH, 6242 Kronberg-Taunus, Pferdstasse 1, Federal Republic of Germany

Published for the Commission of the European
Communities; Directorate General Scientific and
Technical Information and Information Management,
Luxembourg

Copyright © 1979 ECSC, EEC, EAEC Luxembourg
*All Rights Reserved. No part of this publication may be
reproduced, stored in a retrieval system or transmitted
in any form or by any means: electronic, electrostatic,
magnetic tape, mechanical, photocopying, recording or
otherwise, without permission in writing from the
copyright holders.*

First edition 1979
EUR 6115

British Library Cataloguing in Publication Data

Joint Varenna-Grenoble International Symposium
on Heating in Toroidal Plasmas, *Grenoble, 1978*
Heating in toroidal plasmas.
I. Plasma heating - Congresses
I. Title II. Commission of the European Communities
621.48'4 QC718.5.H5 78-40872
ISBN 0-08-023400-3

*In order to make this volume available as economically
and as rapidly as possible the authors' typescripts have
been reproduced in their original forms. This method
unfortunately has its typographical limitations but it is
hoped that they in no way distract the reader.*

P R E F A C E

For a number of years topical conferences dedicated to the problem of plasma heating have been organized independently in France, first at Saclay and then at Grenoble, and in Italy at Varenna.

The conferences in France have been organized by the Département de Physique du Plasma, Association EURATOM-C.E.A. through its "Service d'Ionique Générale". The Varenna conferences have been organized by the "Laboratorio di Fisica del Plasma - EURATOM-CNEN" of the Università di Milano.

The considerable success of these conferences and the increasing interest in specialized symposia on the crucial problem of plasma heating has led to a decision to hold in Grenoble a Joint Varenna-Grenoble Symposium on Heating in Toroidal Plasmas.

The Symposium is sponsored by the European Physical Society and the Société Française de Physique through their Plasma Physics Divisions, by the Commission of the European Communities and by the Commissariat à l'Energie Atomique.

The programme and the invited lectures have been proposed and selected by an International Steering Committee.

This volume contains the texts of the contributed papers presented at the Symposium. The second volume contains the invited lectures and the post dead-line papers. No editorial work has been carried out. Reproduction by photographic process means that the authors bear responsibility for their texts.

The Organizing Committee

T. CONSOLI — P. CALDIROLA

I N T E R N A T I O N A L S T E E R I N G C O M M I T T E E

- D. BISKAMP, Max-Planck Institut, Garching, Federal Republic of Germany.
- E. CANOBBIO, Association EURATOM-CEA, Centre d'Etudes Nucléaires
de Grenoble, Grenoble, France.
- J.F. CLARKE, Department of Energy, Washington D.C., U.S.A.
- B. COPPI, Massachusetts Institute of Technology, Cambridge, U.S.A.
- J.L. DELCROIX, Université Paris-Sud, Orsay, France.
- B.D. FRIED, University of California, Los Angeles, U.S.A.
- V.E. GOLANT, A.F. Ioffe Physical-Technical Institute, Leningrad, U.S.S.R.
- G. GRIEGER, Max-Planck Institut, Garching, Federal Republic of Germany.
- T. OHKAWA, General Atomic Company, San Diego, U.S.A.
- D. PALUMBO, Commission of the European Communities, Brussels, Belgium.
- M.S. RABINOVITCH, P.N. Lebedev Physical Institute, Moscow, U.S.S.R.
- F. SANTINI, Associazione EURATOM-CNEN sulla Fusione, Centro Gas Ionizzati,
Frascati, Italy.
- T.H. STIX, Plasma Physics Laboratory, Princeton, U.S.A.
- D.R. SWEETMAN, Culham Laboratory, Abingdon, United Kingdom.
- T. TAKAYAMA, Institute of Plasma Physics, Nagoya, Japan.
- V.T. TOLOK, Physico-Technical Institute, Kharkov, U.S.S.R.
- P. VANDENPLAS, Ecole Royale Militaire, Brussels, Belgium.
- J. WILLIS, Department of Energy, Washington D.C., U.S.A.
- K. YAMAMOTO, Japan Atomic Energy Research Institute, Tokyo, Japan.

ORGANIZING COMMITTEE

- T. CONSOLI - Association EURATOM-CEA, Centre d'Etudes Nucléaires de Grenoble, Grenoble, France.
- P. CALDIROLA - Associazione EURATOM-CNR, Università di Milano, Milan, Italy.

CHAIRMEN

- T. CONSOLI - Association EURATOM-CEA, Centre d'Etudes Nucléaires de Grenoble, Grenoble, France.
- W.H. HOOKE - Plasma Physics Laboratory, Princeton, U.S.A.

SCIENTIFIC SECRETARIES

- O. DE BARBIERI - Association EURATOM-CEA, Centre d'Etudes Nucléaires de Grenoble, Grenoble, France.
- C. GORMEZANO - Association EURATOM-CEA, Centre d'Etudes Nucléaires de Grenoble, Grenoble, France.
- E. SINDONI - Associazione EURATOM-CNR, Università di Milano, Milan, Italy.

TECHNICAL ASSISTANTS

Miss J. VERCIER, Manager
B. BARRY
Mr. and Mrs. L. DUPAS
J. LUTY

Mrs. S. VASSALO
J. J. CAPITAIN
J. LECOMTE
D. TEBOUL

Association EURATOM-CEA
Département de Physique du Plasma et de la Fusion Contrôlée
Service d'Ionique Générale, Centre d'Etudes Nucléaires de Grenoble
85 X - 38041 GRENOBLE CEDEX (France)

FINANCIAL SUPPORT

The organizations listed below have contributed financially to the Symposium.

COMMISSARIAT A L'ENERGIE ATOMIQUE, PARIS
COMMISSION DES COMMUNAUTES EUROPEENNES, BRUSSELS

This page intentionally left blank

C O N T E N T S

GENERAL THEORY

J.W. CONNOR, J.B. TAYLOR - Implications of Theoretical Scaling Laws.	1
P. JAVEL - On the Use of Duality and Complex Vectorial Space for the Orthonormal Decomposition of the Electromagnetic Field in Anisotropic Media.	5

NEUTRAL BEAM INJECTION

J.A. ROME, Y-K. M. PENG - The Topology of Tokamak Orbits.	7
A.A. MIRIN et al. - Fokker-Planck/Transport Analyses of Fusion Plasmas in Contemporary Beam-Driven Tokamaks.	13
C.E. SINGER et al. - Evolution of Neutral-Beam-Driven Current in Toka- mak Plasmas.	19
J.D. STRACHAN et al. - Fusion-Neutron Production in Deutérium-Beam- Heated Plasmas in the Princeton Large Tokamak.	25
K. TANI et al. - Behaviour of Fast Ions in a Large Tokamak Plasma during NBI Heating.	31
D.F.H. START et al. - Observation of Beam-Induced Currents in a Toroidal Plasma.	37
P.J. LOMAS et al. - Neutral Injection Heating of Cleo Stellarator - Theory and Experiment.	43
G.H. NEILSON et al. - Injection-Dominated Tokamak Experiments at ORNL.	49
T. KURODA et al - Neutral Beam Injection in JIPP T-II Device.	55

P. KUPSCHUS, C. MEIXNER - Neutral Injection Parameters for TEXTOR and Beam Line Design Considerations.	61
H.H. HASELTON et al. - PLT and ISX Neutral Beam Injectors.	67
P. RAIMBAULT, M. FUMELLI - The Development of a Peripheral Electrostatic Energy Recovery System for Neutral Beam Injectors.	71
A.P.H. GOEDE et al. - Development of Large Volume Magnetic Multipole Ion Sources.	77
R.S. HEMSWORTH et al. - The DITE Phase II Neutral Injection System.	83
A.C. WAGER et al. - Electrode Power Loading in High Current Ion Sources.	89

HEATING AT ION CYCLOTRON- AND LOWER FREQUENCIES

H.W. KALFSBEEK - Heating of a Toroidal Plasma by Skin Current.	97
D. MOREAU - Low Frequency Parametric Processes in Magnetically Confined Plasmas.	103
T. OBIKI et al. - Shear Alfvén Wave Heating Experiments in HELIOTRON D.	109
E. TENNFORS - On the Limitation of RF Fields by Alfvén's Critical Ionization Velocity Phenomenon.	115
A. HASEGAWA - Nonlinear Processes of the Alfvén Wave Heating.	119
J.E. SCHARER et al. - Fast Wave Heating via Mode Conversion and ICRF Scaling to Reactor Size.	121
J. JACQUINOT - ICRF Heating of a Tokamak in a Proton-Deuteron Mixture.	127
V.P. BHATNAGAR et al. - Magnetosonic Resonance Heating in the ERASMUS Tokamak.	133

Y.YASAKA, R. ITATANI - Ion Cyclotron Heating by Azimuthally Rotating RF Fields.	139
 <u>LOWER HYBRID RESONANCE HEATING</u>	
K. OHKUBO, K. MATSUURA - Lower Hybrid Wave Heating in JIPP T-II.	145
C.P. MOELLER et al. - Lower Hybrid Wave Heating in DOUBLET IIA.	151
S. TAKAMURA, T. OKUDA - Basic Experiment at LHR Frequency Range in Octopole Tokamak.	155
S.S. PESIC - Parametric Instabilities in Weakly-Inhomogeneous Hot Plasmas.	161
E. LAZZARO, C. MAROLI - Antenna Impedance in the Lower Hybrid Region.	167
P.K. SHUKLA et al. - Filamentation and Spatial Attenuation of the Lower-Hybrid Waves in Tokamaks.	173
A.K. SUNDARAM, A.C. DAS - Tearing Mode Instabilities and their Suppression by Lower Hybrid Fields.	177
S. SUCKEVER et al. - Impurity Radiation during RF Heating in ATC.	181
N.J. FISCH - Steady-state Tokamak Reactors with RF-Driven Currents.	183
F. SANTINI, M. TONON - Ray Trajectory and Ion Absorption of LH Waves in a Tokamak.	185
G. ICHTCHENKO - Lower Hybrid Wave Propagation and Parametric Decay in the WEGA Tokamak.	187
M. FICHET, I. FIDONE - Effect of the Slow-Fast Mode Conversion on the Lower Hybrid Slow Mode Excitation.	189

ELECTRON CYCLOTRON HEATING

D.B. BATCHELOR et al. - A theoretical Study of Microwave Heating in ELMO Bumpy Torus.	191
S. TANAKA et al. - Wave Trajectory and Electron Cyclotron Heating in Toroidal Plasmas.	197
O.C. ELDRIDGE et al. - Wave Heating of Toroidal Plasmas at Electron Cyclotron Resonances Harmonics.	203
M.J. SMITH, J. RANDALL - Considerations on the Design of a 50 GHz Gyrotron.	209
G. MOURIER - Some Space Charge Phenomena in Gyrotrons.	215
M. BORNATICI, F. ENGELMANN - Ordinary and Extraordinary Mode in an Inhomogeneous Plasma in the Presence of Electron Runaways.	221
S. CORTI et al. - RF Preionization in Tokamak THOR : Effect of Subharmonics of Ω_0 on the Absorption of the Wave.	225
V. STEFAN - Nonlinear Dissipation of a Finite Bandwidth Radiation in a Plasma near Electron Cyclotron Harmonic Resonances.	231

<u>AUTHOR INDEX</u>	237
---------------------	-----