330
11/16/78

DOE/ET-0069

LD. 731

MASTER

Experimental Plasma Research Project Summaries

August 1978

U.S. Department of Energy
Assistant Secretary Energy Technology
Office of Fusion Energy
Division of Applied Plasma Physics
Experimental Plasma Research Branch

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

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.

DISCLAIMER

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

Experimental Plasma Research Project Summaries

August 1978

**U.S. Department of Energy
Assistant Secretary Energy Technology
Office of Fusion Energy
Division of Applied Plasma Physics
Experimental Plasma Research Branch
Washington, D.C. 20545**

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or 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.

Available from:

**National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161**

Price: **Printed Copy:** \$ 7.25
 Microfiche: \$ 3.00

TABLE OF CONTENTS

	Page
Preface	v
Introduction	1
Personnel	2
Funding Summary	3
 Plasma Properties (PP) Program	 4
Los Alamos Scientific Laboratory	6
Princeton Plasma Physics Laboratory	8
University of California at Los Angeles	10
University of California at Los Angeles	12
University of California at Irvine	14
Columbia University	16
University of Maryland	18
University of Maryland	20
Massachusetts Institute of Technology	22
Pennsylvania State University	24
University of Santa Clara	26
University of Texas	28
University of Wisconsin-Madison	30
University of Wisconsin-Madison	33
 Plasma Heating (PH) Program	 35
Princeton Plasma Physics Laboratory	37
Naval Research Laboratory	40
California Institute of Technology	42
University of California at Los Angeles	44
Massachusetts Institute of Technology	46
Massachusetts Institute of Technology	48
University of Wisconsin-Madison	52
 Measurements and Instrumentation (MI) Program	 54
Los Angeles Scientific Laboratory	56
Lawrence Livermore Laboratory	58
Princeton Plasma Physics Laboratory	61
Oak Ridge National Laboratory	63
The Aerospace Corporation	65
American Science and Engineering, Inc.	67
University of California at Los Angeles	69
University of California at San Diego	71
Johns Hopkins University	73
University of Maryland	75
University of Maryland	77
Massachusetts Institute of Technology	79
Rensselaer Polytechnic Institute	81
Smithsonian Institution, Astrophysical Observatory	84

	Page
Atomic, Molecular and Nuclear Physics (AM) Program	86
Lawrence Berkeley Laboratory	88
Lawrence Berkeley Laboratory	91
Oak Ridge National Laboratory	93
Oak Ridge National Laboratory	96
National Bureau of Standards	98
Naval Postgraduate School	102
Naval Research Laboratory	104
Naval Research Laboratory	106
Georgia Institute of Technology	108
University of Maryland	110
Wesleyan University	112
University of Western Ontario	114
 Advanced Superconducting Materials (S/C) Program	 117
Massachusetts Institute of Technology	119
 Fusion Plasma Research Facility (FPRF) Program	 123
University of Texas	124

PREFACE

This report contains descriptions of the activities supported by the Experimental Plasma Research Branch of APP. The individual project summaries were prepared by the principal investigators and include objectives and milestones for each project. The projects are arranged in six research categories: Plasma Properties; Plasma Heating; Plasma Measurements and Instrumentation; Atomic, Molecular and Nuclear Physics; Advanced Superconducting Materials; and the Fusion Plasma Research Facility (FPRF). Each category is introduced with a statement of objectives and recent progress and followed by descriptions of individual projects. An overall budget summary is provided at the beginning of the report.

The report will be distributed to various segments of the fusion community and will serve several purposes. For scientists in the field, it is intended that the report will help provide the information about on-going programs needed to improve communications among scientists and with the Branch. For ETM staff, the primary purpose is to improve coordination between the Experimental Plasma Research Branch and other branches within the Office.

We intend to issue the report in the early Fall of each future year so that it will serve as an annual report.

Philip M. Stone, Acting Chief
Experimental Plasma Research Branch
Division of Applied Plasma Physics
Office of Fusion Energy

INTRODUCTION

The Experimental Plasma Research Branch has responsibility for supervising a broad spectrum of experimental data and new experimental techniques that are required for operating and interpreting present large-scale confinement experiments, and for designing future deuterium-tritium burning experiments.

The Branch pursues these objectives by supporting research in DOE laboratories, other Federal laboratories, universities, and industry. Initiation and renewal of research projects are primarily through submission of unsolicited proposals by these institutions to DOE.

The objectives, as stated above, result in support of a wide variety of plasma physics research, as well as some specific areas of atomic and nuclear physics and superconducting research that are important to ETM. The research has been divided into six categories for budgeting and planning purposes as follows: Plasma Properties (PP); Plasma Heating (PH); Measurements and Instrumentation (MI); Atomic, Molecular and Nuclear Physics (AM); Advanced Superconducting Materials (S/C); and the Fusion Plasma Research Facility (FPRF). A breakdown of funding by category and by type of institution is provided. The general objectives, recent progress, and project descriptions for each category are included.

The Fusion Plasma Research Facility is a medium-sized tokamak at the University of Texas at Austin. This project was initiated in FY 1977 and operation is scheduled for FY 1980. This device will be a national facility available to experimenters from throughout the nation. Research in all of the categories of the present experimental research program is appropriate for this facility as well as plasma-surface studies. This project is described in a separate section of this report.

The funding summary shows a decrease of nearly \$2.0 million in 1978 for the total operating budget. The overall decrease in the funding of the five research areas is approximately \$3.6 million in operating budget and about \$1.1 million in equipment budget. The decrease in the level of activity, however, is less than the budget would suggest. This is because large fabrication projects at Maryland and Columbia were completed in 1977 and because approximately \$2.0 million in 1977 was used to provide 2-year funding at several institutions (so that funding in 1978 was not required at these institutions). The research activity in 1978 and anticipated in 1979 is actually about level from 1977 excluding the FPRF.

The Branch has been reorganized in recent weeks and additional personnel have been added. Donald Priester has moved over from the Theory Branch and Milton Johnson has joined from the Mirror Branch. The Alternate Concepts activity has moved into the new Advanced Fusion Concepts Branch. Areas of responsibility for each staff member are shown in the following table.

Experimental Plasma Research Branch

Personnel

Staff Member	Area of Responsibility
Philip M. Stone	Acting Branch Chief
Donald H. Priester	Atomic, Molecular and Nuclear Fusion Plasma Research Facility
James M. Turner	Plasma Heating Measurements and Instrumentation
Milton D. Johnson	Plasma Properties Superconducting Materials

FUNDING SUMMARY

(In Thousands of Dollars)

	1977	1978 (Est.)
OPERATING BUDGET		
<i>Area</i>		
PP	3,650	2,300
PH	2,550	980
MI	2,645	2,275
AM	1,690	1,465
S/C	165	330
FPRF	800	2,250
Total Operating	11,500	9,600

EQUIPMENT BUDGET

<i>Area</i>		
FPRF	---	2,000
Other	1,630	525
Total Equipment	1,630	2,525

OPERATING BUDGET

<i>Institution</i>		
DOE Lab	3,100	2,475
University	7,560	5,700
Industry	90	390
Federal Lab	750	1,035
	11,500	9,600

PLASMA PROPERTIES (PP) PROGRAM

Experimental studies in this area are aimed at providing tests, quantitative where possible, of analytic and computer models of plasma behavior. These studies are pursued either on small special purpose experiments or on fairly sizable machines with magnetic geometries similar to the mainline confinement devices, tokamaks and magnetic mirrors. Some tokamak-related objectives include the measurements of trapped particle effects, energy and particle transport across magnetic fields, and the development of new techniques for obtaining clean plasmas. Objectives for magnetic mirrors include the study of methods to stabilize the DCLC mode, the study of energy scaling with large mirror ratios and methods to stabilize MHD flute modes in non-Min $|B|$ systems. Measurements from these experiments complement data from larger machines and provide a broader information base for design of large confinement devices.

Progress—Plasma Properties

- Experiments on Macrotor have shown that impurities released from tokamak surfaces are caused primarily by ions bombarding the walls after acceleration through the plasma-wall sheath. These unique and important experiments have shown that the impurity influx can be significantly reduced when the sheath potential is reduced.
- The first phase of experiments on drift cyclotron loss cone (DCLC) stabilization by electron beam injection has been completed at MIT. The hot-electron temperature and diamagnetism have been measured over a range of injected E-beam power, and the effect on DCLC amplitude has been plotted. MIT has determined the approximate lengths of the trapped plasma and of the beam-produced hot-electron component by diamagnetic measurements. The plasma turns out to be fairly short, ~ 20 cm and is trapped in a shallow ($\sim 1.2/1$) mirror. The hot electrons are about 50% longer than the plasma ion distribution, and thus are very different from Ioffe's presumed concentration very close to the mid-plane.
- Divertor simulation experiments have been successfully conducted by the University of Wisconsin. Density, potential, and particle flux have been measured in the vicinity of the $\bar{E} \times \bar{B}$ poloidal divertor in the levitated octupole and a four node poloidal divertor configuration has been achieved in Tokapole II.
- An improved discharge cleaning technique for tokamaks has been developed on Microtor and is being used on PLT. A low temperature AC discharge is used for cleaning which forms H_2O vapor that is pumped out in the normal manner. Oxygen on the inner surfaces of the vacuum vessel is reduced in this manner to about 1 percent of a monolayer and tokamak discharges with oxygen content as low as 10^{10} atoms/cm³ can be produced. The concentrations of carbon impurities are also reduced.
- Preliminary tests of injection of plasma into the 2X-IIB mirror machine by the deflagration plasma gun at Santa Clara have been completed. The gun is one possible means of fueling large devices. It will also be tested on the Microtor tokamak.
- In Thor at Maryland, the first direct observation of tearing modes on neutral sheets was made. These magnetic field measurements demonstrate that reconnection of the inner and outer axial flux leads to the formation of closed magnetic surfaces which should result in greatly improved electron energy confinement over an open field system.

Project

Plasma Properties, Experimental

J. C. Ingraham, R. S. Massey, B. L. Wright

FY77 \$400K op FY78 \$417K op
10K op

Purpose

To study electron heat flow and thermal conductivity parallel to $\vec{B}_0$ in a linear magnetically confined plasma column under a variety of conditions that could exist in a fusion reactor, to study plasma AC and DC resistivity, and to investigate means of plasma heating such as high-frequency beat-heating.

Approach

A Q-machine plasma column is used to study electron heat flow parallel to the magnetic field, microwave absorption and plasma heating, and AC and DC electrical resistivity. Several microwave resonators separated in space along the plasma column are used to provide local heating and electron temperature measurements for heat flow investigation. A one-dimensional time- and space-dependent heat flow computer code is used to analyze the heat flow data. Dual- and Single-Mode resonators are used to measure plasma AC resistivity under conditions of: excitation of controlled levels of fluctuations; and DC electric current flow in the column. Retarding potential energy analyzers are used to measure electron velocity distributions produced by parametric instabilities.

A multipole-confined plasma device is used to study high frequency beat-heating of a plasma in a waveguide.

Progress

Our main experimental system (Q-machine) has been moved to a new location to allow construction to proceed on a large toroidal reversed-field pinch (ZT-40). Our experiment has been re-assembled, and most components tested in the new location. Preparations are under way to allow direct computer data collection and processing in our Q-machine experiments. Significant progress in preparation of two papers has been made: "Observation of Negative Inverse Bremsstrahlung Absorption Due to Strong DC Electron Drifts" and "Weak-Field Microwave Resistivity in a Turbulent Plasma." Progress on the plasma beat-heating experiment has been delayed so as to allow a more rapid reassembly of the Q-machine experiment.

Plans

1. Measure electron heat flow in our Q-machine in the presence of strong local temperature gradients and electrostatic trapping.

2. Make preparations for study of the effects of magnetic mirrors, particle end loss, and plasma turbulence on heat flow.
3. Continue studies of AC and DC resistivity in presence of turbulence.
4. Continue studies on high-frequency plasma beat-heating.
5. Make the scientific information obtained available through publications, seminars, and personal exchanges.

Milestones

1. Measure and analyze heat flow data in the presence of strong local temperature gradients—January 1979.
2. Evaluate electron cyclotron heating as an alternate means of producing strong local electron temperature gradients for heat flow studies—February 1979.
3. Measure and analyze heat flow data in the presence of electrostatic trapping potentials—August 1979.
4. Measure plasma heating at the beat frequency of two travelling electromagnetic waves—August 1979.

Graduate Students

None

Graduates

None

Other Professional Staff

None

Major Recent Publications

None

Project

Q-1, QED-1: Plasma Properties and Divertor Simulation

M. Yamada

FY77 \$280K op
19K eq

FY78 \$300K op
15K eq

Purpose

To investigate particle and heat transport in a flowing plasma which simulates the divertor scrape-off region and to obtain fundamental physics data on particle gettering, plasma collection, boundary conditions, impurity backflow, and shock formation (QED-1).

To investigate waves, and collective phenomena in high (QED-1) and low (Q-1) β plasmas, including physics simulation study of trapped-ion modes and waves driven by neutral-beam injection and α particle plasma-interaction.

Approach

QED-1 (Quiet, Energetic, Dense Plasma) utilizes a 75-kW arc to provide a finite- β plasma column 128 cm in length ($\beta = 10^{-4} \rightarrow 10^{-1}$), 1.5 cm in diameter with $n_e = 10^{15} \text{ cm}^{-3}$, $T_i \approx T_e \lesssim 20 \text{ eV}$.

The present Q-1 machine provides an isothermal low β plasma for the study of transport, waves (trapped ion modes, drift waves), instabilities and linear and nonlinear wave-particle interactions.

Progress

1. The sputtering yields of H^+ , D^+ , He^+ (with $E \approx 20 \sim 300 \text{ eV}$) on various tokamak limiter material were measured for the first time in a relevant plasma environment. Other experiments, pertinent to gettering efficiency in a divertor burial chamber, revealed sticking coefficients below 10% for H and D on titanium.
2. In the Q-1 device, anomalous slowing of an ion beam injected perpendicularly to the confining magnetic field of a low- β plasma was experimentally observed and attributed to the nonlinear beam-excited lower-hybrid instability.
3. In the QED-1 device, a physics study of gas-plasma interaction, i.e., a gaseous plasma collector, has been started.
4. In the Q-1 device, a parametric lower-hybrid instability, driven by a modulated electron beam, has been experimentally identified and studied intensively.
5. An experiment has been initiated to simulate the trapped ion mode in a tokamak.

Plans

1. The microstability of finite- β plasmas will be investigated in QED-1.
2. In QED-1, simulation of particle and heat transport in a divertor plasma will be carried out, and the feasibility of a gaseous collector will be investigated.
3. In Q-1 new types of ion-beam injection experiments which simulate α particle plasma interaction and trapped-ion-instability (with a mirror field) are carried out.
4. A low-aspect ratio, low field, toroidal plasma, for basic-physic investigations.

Milestones

1. Completion of a design study of small-scale, low-aspect ratio toroidal device, and to start the fabrication of the device. The QED-1 gun will be used to generate an initial plasma—June 1979.
2. The trapped-ion instability study will be coordinated with PLT microwave-scattering experiments, and initial data obtained—September 1979.
3. The microstability of finite- β plasmas will be investigated in QED-1—June 1979.
4. First data on the feasibility of a gaseous collector will be obtained—February 1979.

Graduate Students (% DOE support, degree, year to complete)

G. Allen (100, Ph.D. 2)
R. MacKay (100, Ph.D. 4)

Other Professional Staff

P. Barrett, M. Nishi

Major Recent Publications

Yamada, M., Seiler, S., Hendel, H., and Ikezi, H., *Phys. Fluids* **20**, 450-458 (1977).

Yamada, M. and Hendel, H. W. Hendel, to be published in *Phys. Fluids* **21**, Sept. (1978).

Yamada, M. and Owens, D. K., *Phys. Rev. Lett.* **38**, 1529 (1977).

Yamada, M. and Seiler, S. W., *Phys. Rev. Lett.* **39**, 808 (1977).

Seiler, S. and Yamada, M., submitted to *Phys. Fluids* (Dec. 1977).

M. Yamada, *Bull. Am. Phys. Soc.* (invited paper) **22**, 1199 (1977).

Project

Large Mirror Facility (LMF)

A. Y. Wong

FY77 \$125K op
0 eq

FY78 \$125K op
0 eq

Purpose

1. Produce a MHD stable mirror confined plasma of large diameter and uniform density.
2. Study confinement with high mirror ratio.
3. Study properties of loss cone instabilities and their effect on confinement.

Approach

An average minimum $|\beta|$ magnetic field configuration is produced by combining a surface magnetic field with a simple mirror field. This produces a region of large axial (100 cm) and radial (60 cm) dimensions with uniform field strength. Low central field strength (200 G) allows high mirror ratio at a moderate mirror throat field (4kG). The uniform field region will allow detailed study of loss cone instabilities.

Progress

Magnetic field design is complete and coils are being constructed. Vacuum system and power supply construction has begun. A washer stack gun plasma source has been designed and is being constructed.

Plans

1. Evaluate the effectiveness of a surface magnetic field in stabilization of a simple mirror.
2. Verify the presence of a loss cone ion velocity distribution. Study the effect of mirror ratio and micro instability level on confinement and velocity distribution.
3. Study the properties of the drift cyclotron loss cone instability.

Milestones

1. Initial operation of experiment—October 1978.
2. Study dependence of plasma parameters on mirror ratio—February 1979.

3. Study large plasma diameter stabilization of the drift cyclotron loss cone instability—
June 1979.

Graduate Students (% DOE support)

D. Eggleston (0), J. Ferron (50), K. Jones (0), P. Lee (0), P. Leung (0), J. Levy (50),
R. Schumacher (100), J. Santoru (0), N. Wild (0), W. DiVergilio (0).

Graduates (Year)

D. Mamas (1977)

Other Professional Staff

F. Brunel, G. DiMonte, M. Fukao, Q. Tran

Major Recent Publications

1. "Fast Ion Beam-Plasma Interaction System", R. A. Breun, J. R. Ferron, submitted to Review of Scientific Instruments.
2. "Fast Ion Beam-Plasma Kinetic Instability", J. R. Ferron, R. A. Breun, A. Y. Wong, Bull. Am. Phy. Soc. 22, #9, 1097 (1977).

Study of Hot Plasma Transport and Heating in Toroidal Geometry

FY77	\$535K op	FY78	\$225K op
			.5K eq

Research under this project is geared towards the production of clean tokamak plasmas, the study of heating and particle transport, scaling and the limiting processes of beta, radiation and power input.

Plasmas are produced in Microtor and Macrotor tokamaks by using capacitor banks up to 5 MJ. Fields of 25 kG have been produced in Microtor and of 2 kG in Macrotor. The dimensions are $R \approx 30$ cm and a chamber cross section of 20 x 25 cm for Microtor, and $R = 100$ cm with a 90 x 150 cm chamber for Macrotor.

1. Operated Macrotror for one year at 2 kG.
2. Demonstrated the suppression of high-Z impurity influx by cold electron injection (which changes the sheath potential).
Macrotror shows the scaling na^2 to hold at 2 kG.
3. Operated Microtror at 20 kG—August 1978.

1. To study the suppression of impurity influx at high density.
2. To measure sputtering rates.
3. To study power balance and its dependence on internal fluctuations.
4. To study high beta limits.
5. To study transport in the presence of RF.

Milestones

1. Operate Macrotror at 5 kG—September 1978.

Graduate Students (% DOE support)

D. Whelan (100%, summer; 50%, academic year), C. Menyuk (100%, summer)

Graduates

None

Other Professional Staff

J. Carter	S. Talmadge
L. Oren	S. Zweben

Major Recent Publications

Lena Oren and R. J. Taylor, *Suppression of Impurities by a Cold Electron Injection in Macrotror*, to be submitted to Physical Review Letters.

Project

Flute Stabilization in a Simple Mirror

Nathan Rynn; Norman Rostoker

6/77 to 6/79 \$159K

Purpose

To stabilize a simple mirror confined plasma against flute instabilities by surrounding it with an outer blanket of cold plasma that is line-tied to an electron-emitting conductor.

Approach

The plasma core is generated by a Q-machine hot plate. With a pulsed cusped magnetic field or with a pulsed grid the plasma column can be electrically isolated from the hot plate. The plasma becomes de-line-tied and is susceptible to magnetic field curvature driven flutes. A second, annular hot plate forms a tenuous plasma surrounding the core. Flute stabilization by this line-tying blanket is being investigated.

Progress

1. The annular hot plate has been built and tested.
2. Diagnostic techniques for detecting radial and azimuthal plasma motion have been developed.
3. Two methods of electrically isolating the plasma core from the hot plate have been built and tested.
 - a. The pulsed cusped magnetic field was found to produce a radial electric field in the plasma column and therefore produces a undesirable plasma rotation.
 - b. A grid between the hot plate and the plasma column was found to effectively isolate the two. At the same time, if biased negatively, the grid provides for electrostatic electron trapping.
4. A high density ($n \sim 10^{14} \text{ cm}^{-3}$) plasma source was developed which is being tested for cross field injection.
5. Verified cross field injection of high density plasma in August of 1978.

Plans

1. Determine the motion of the stable core both with and without the conducting blanket.
2. Determine the motion of a flute-unstable core both with and without the conducting blanket.
3. Repeat these measurements using a barium plasma and optical diagnostics to measure the heat loss from the core to the tenuous plasma blanket.

Milestones

1. Measure and compare flute excitation and stabilization—December 1978.
2. Measure radial heat transfer—May 1979.

Graduate Students

None

Graduates

None

Other Professional Staff

H. Boehmer 25%
Y. Kiwamoto 100%

Major Recent Publications

None

Project

High-Beta Plasma Research - Torus I and II

Robert A. Gross; C.K. Chu

FY 77	710K op.	FY 78	30K op.
	170K eq.		60K eq.

Purpose

To investigate plasma equilibrium and stability of high-beta axisymmetric toroidal configurations.

Approaches

Torus I is an axisymmetric, rectangular cross section experimental device ($R_0 = 22.5$ cm, $R_0/a = 3$, $h = 45$ cm), which operates as a belt pinch or elongated high-beta tokamak. Operating parameters are: $B_0 \sim 10$ kG, $n \sim 10^{16} \text{ cm}^{-3}$, $T \sim 10$ eV, $I_p \sim 110$ kA, $q(a) \gtrsim 3$, $\langle \beta \rangle \sim 10\%$

Torus II is an axisymmetric, rectangular cross section, high-beta tokamak ($R_0 = 22.5$ cm, $R_0/a = 3$, $h = 30$ cm) heated by a fast ($1.7 \mu\text{sec}$) toroidal field reversal technique. Operating parameters are: $B_0 \sim 10$ kG, $n \sim 10^{15} \text{ cm}^{-3}$, $T > 100$ eV, $I_p \sim 80$ kA, $q(a) \gtrsim 2$, $\langle \beta \rangle \sim 5\text{-}10\%$.

Progress

Torus I: Completed survey of Torus I operation in belt pinch and high-beta tokamak modes. Completed preionization effects study. Operated Torus I with, and without, a limiter. Magnetic field mapping and laser Thomson scattering measurements were obtained. Plasma filaments were observed which are believed to be tearing mode instability. Schlieren optical system is being developed.

Torus II: Construction completed, October 1977. Shakedown of electrical system completed April 1978. Diagnostics: magnetic field probes, Rogowski coils, x-ray detection system, visible spectroscopy, Ashby-Jephcott $3.39 \mu\text{m}$ interferometer are now installed and operating: UV vacuum spectroscopy and CO_2 laser scattering diagnostics are being developed.

Plans

Torus I: Complete field mapping with and without limiter. Complete measurements of $\langle \beta \rangle$, and determine why filamentary plasma structure occurs. Complete schlieren diagnostic and evaluate this optical technique for toroidal plasma research.

Torus II: Complete operating parameter survey. Measure plasma properties and determine $\langle \beta \rangle$. Begin stability studies of high-beta tokamak configurations. Search for ballooning modes.

Milestones

1. Begin detailed studies of Torus II plasma properties—October 1978.
2. Obtain first schlieren and shadowgraph pictures of Torus I plasma—January 1979.
3. Begin detailed studies of Torus II equilibrium and stability—January 1979.
4. Complete study of Torus I magnetic field structure with and without limiter—July 1979.
5. Complete study of β decay and filamentary structure in Torus I—July 1979.

Graduate Students (% DOE Support)

G. Georgiou (100%); J. Marsen (100%); S. Paul (100%); C. Kostek (100%); A. Kashani (0%).

Graduates (Year)

B. Feinberg (1974), D. McNeill (1974), L. Scaturro (1975).

Other Professional Staff

Professor T.C. Marshall
Professor G.A. Navratil

Dr. P.G. Weber
Dr. Z. Mucha

Major Recent Publications

1. Experimental and Theoretical Studies of High-Beta Tokamaks, A. Aydemir, et al., IAEA-CN-37-U1, 7th International Conf. on Plasma Physics and Controlled Nuclear Fusion Research, Innsbruck, Austria, August 1978 (to be publ.).
2. Columbia Torus II, A High-Beta Tokamak: R.A. Gross, P.G. Weber, T.C. Marshall; Proc. IEEE Workshop, Monterey, Calif., May 1978 (to be publ.).
3. High-Beta Tokamaks by Pinch Techniques; C.K. Chu, R.A. Gross; Proc. Finite-Beta Tokamak Workshop, Varenna, Italy, Sept. 1977 (to be publ.).
4. Fusion Energy; R.A. Gross, ASME Jour. of Engr. for Power, July 1978.
5. Prospects for a High-Beta Tokamak; R.A. Gross, Comments Plasma Phys. Fusion 3, 103 (1977).

Project

Production of Thermonuclear Plasmas in High Beta Devices

H. R. Griem, A. DeSilva, C. Chin-Fatt, and G. Goldenbaum

FY77	\$400 op	FY78	\$400K op
	274 eq		0 eq

Purpose

To study the heating, confinement, and stability of high beta plasmas.

Approach

Deuterium plasmas are produced and heated in a toroidal theta pinch by the application of fast rising ($t/4 < 1 \mu s$), high voltage (600 kV), pulses which are crowbarred at peak current and decay with an L/R time of $30 \mu s$. A post-implosion "quasi-equilibrium" phase is attained by programming an additional capacitor bank to drive toroidal plasma currents.

Progress

Spatially resolved measurements of the magnetic field, electron density, and temperatures provided strong evidence for the role of microinstability heating of the electrons in the current sheath. X-ray and Thomson scattering measurements revealed a bi-Maxwellian electron distribution with a bulk component at about 200 eV and a smaller hot component at $T > 1$ keV. Ion temperatures from neutron yields and Doppler broadening of impurity spectral lines are > 1 keV, all at $n \approx 10^{15} \text{ cm}^{-3}$ and in a quartz torus. Experiments on the heating and confinement of deuterium plasmas at $2/3$ maximum voltage were also made using a plastic torus coated with a refractory material. By optimizing the toroidal current driver, we were able to maintain the high beta plasma for periods greater than $5 \mu s$ with no evidence of MHD instability. Detailed comparisons of these results have been made with particle simulation codes and ideal MHD equilibrium models.

Plans

Spectroscopic studies of plasma impurities are planned and a comparison of plasma properties will be made when the quartz torus is reinstalled. More detailed measurements of plasma properties during the equilibrium phase will be made, and methods of maintaining the high beta plasma for longer periods of time will be investigated. Tearing and ballooning modes will be of particular interest.

Milestones

1. Complete heating and equilibrium studies—September 1979.
2. Complete stability and late time transport studies—September 1980.
3. Convert to alternate configuration—June 1981.

Graduate Students

R. Merlino (100%), D. Murphy (100%)

Graduates

None

Other Professional Staff

Dr. Y. P. Chong, Research Associate
Dr. R. A. Hess, Research Associate

Major Recent Publications

Plasma Heating in a High-Voltage Toroidal θ Pinch, Y. G. Chen, et al., Phys. Rev. Lett. 38, 1400 (1977).

Experimental and Theoretical Studies of High-Beta Tokamaks, A. Aydemir, et al., 7th IAEA Conf. on Plasma Physics and Controlled Nuclear Fusion Research, Innsbruck, Austria, 1978.

Project

TERP: Toroidal Experimental Research Plasma

G. C. Goldenbaum

FY77	\$90K op	FY78	\$100K op
	88K eq		0 eq

Purpose

To investigate high beta plasma properties (instabilities and transport) in a noncircular cross section tokamak configuration.

Approach

Energy efficient, pulsed power techniques are used to produce the tokamak configuration via fast rising fields.

Progress

Kink instabilities have been studied in the linear and nonlinear phases and compared with time dependent computer codes. Linear growth rates and dependencies agree well, details in the non-linear phase agree less well.

Transport in a collisional, stable plasma has been investigated, and an MHD regime in which crossed temperature and density gradients coexist has been found.

Plans

Capacitor banks and coil structures are being upgraded to provide higher temperature and longer pulse lengths so that slower high beta effects may be studied (as ballooning and tearing modes).

Milestones

1. Complete installation of new capacitor banks and coils—November 1978.
2. Complete preliminary survey of conditions in upgraded experiment (Terp II)—March 1979.

Graduate Students

J. Antoniadis (100%), B. Weber (100%)

Graduates

A. W. Allen (1978)

Other Professional Staff

None

Major Recent Publications

1. Experimental Observations of the Equilibrium and Stability of a Noncircular Cross Section Toroidal Plasma, A. W. Allen, University of Maryland Technical Report #78-051.
2. Observation of the Nonlinear Phase of a Noncircular Cross Section Toroidal Kink Instability, A. W. Allen and G. C. Goldenbaum, submitted to Phys. Fluids.
3. Observations of a Highly Collisional Toroidal Plasma Equilibrium, A. W. Allen, J. A. Antoniadis, and G. C. Goldenbaum, submitted to Phys. Fluids.
4. Experimental and Numerical Studies of Magnetohydrodynamic Stability Properties of a Rectangular Cross Section Finite β Toroidal Plasma, A. W. Allen, F. L. Cochran, G. C. Goldenbaum, and P. C. Liewer, Phys. Rev. Lett. 39, 404 (1977).

Project

Mirror Instabilities — Constance I

L. D. Smullin

FY77	\$275K op	FY78	\$60K op
	85K eq		10K eq

Purpose

Study of Hot Electron Stabilization of Drift Cyclotron Loss-Cone Instabilities.

Approach

We are producing a small (1-2%) hot electron population by beam-plasma interaction or by ECRH, and observing the stabilizing effect on the DCLC instability of a hot ion (~ 300 ev) plasma confined in a 2:1 mirror with a permanent magnet hexapole. The plasma is injected into the mirror from a Ti washer gun.

Results

We stabilized the DCLC by the injection of a ~ 50 kw electron beam into the plasma. The plasma parameters have been measured as well as the density and temperature of the hot electrons (10^{11} cm^{-3} , ~ 5 kev). (A similar, larger scale test is now being made on 2xII-b at LLL). The results are being written as a Ph.D. thesis for submission September 1978.

Plans

1. We are attempting to duplicate the beam-plasma hot electron production by electron cyclotron heating near the ends of the mirror trapped plasma. A Varian SFD-306, 9.3 GHz pulsed magnetron will be operated at 300-600 kw peak and pulse lengths > 30 -50 μsec (only 1 pulse/ ~ 5 min). This is the only power source available in the US except for some very large and very expensive klystron amplifiers.
2. Very little is understood about the trapping and ion heating in the mirror of the gun injected plasma except that it is an effective way to produce a plasma. We propose to make a systematic set of measurements of the plasma beam parameters and of the intense fluctuations in the mirror during the injection period, in order to lay the basis for a more systematic understanding of this set of phenomena.

Milestones

September 1, 1978 inject rf pulses into plasma (since there are no other magnetrons available, this part of the program may be aborted by an unforeseen accident).

Milestones

September 1, 1978 inject rf pulses into plasma (since there are no other magnetrons available, this part of the program may be aborted by an unforeseen accident).

December 1978 install new diagnostic equipment for plasma trapping studies.

Graduate Students (% DOE support)

R. E. Klinkowstein (100)

M. E. Mauel (100)

to be appointed September 1978 (100)

Graduates

None

Other Professional Staff

None

Major Recent Publications

1. Klinkowstein, R. E., and L. D. Smullin, "Suppression of ω_{ci} Instability in a Mirror-Confined Plasma by Injection of an Electron Beam," Phys. Rev. Lett. **40**, No. 12, 771-773 (1978).
2. Gerassimenko, M., R. D. Petrasso, and R. E. Klinkowstein, "Studies of the Hot Electron Population Created in a Mirror Confined Plasma by Injection of an Electron Beam," to be published.

Project

A Study of Flow and Loss Processes at the End of a Linear Theta Pinch

T. M. York, E. H. Klevans

FY77 \$105K op FY78 \$113 op

Purpose

Investigate the physics of end loss from a theta pinch including mechanisms governing the loss and methods of inhibiting loss to improve confinement.

Approach

Construct a 50 cm long pinch apparatus with a 10 cm diameter discharge coil. Measure the loss rate of plasma within the pinch coil, and correlate measurements with properties (pressure, density and temperature) near and at ends; test the theoretical models of end loss for collisional and collisionless plasmas, with and without magnetic mirrors.

Progress

1. With a 25 cm long, 10 cm diameter theta pinch, detailed experimental studies of the transient loss events have been completed. This discharge apparatus generates a magnetic field of 19.0 kG in 5 μ sec. Theta pinch preionization is on the order of 20% in 100 mT helium, and a new thyatron switch allows main bank initiation with ± 0.1 μ sec accuracy. Following initial evaluation of trapped flux, the transient studies are being carried out for the reversed trapped flux mode. Diagnostic studies that have been carried out include: photography of luminosity (axial and radial at end); local magnetic probing inside the end and coil plasma; spectroscopy of plasma at mid-, quarter-, and end-coil locations to determine n_e , T_e ; local pressure probing inside the discharge tube; flux loops under and in the end loss region; electric probes in the end loss region. Thomson scattering measurements have been made in the end region and correlated with the spectroscopic techniques.
2. A Twyman-Green interferometer system which uses a 7 W He-Ne CW laser has been developed and successfully used to study the loss of plasma from within a 10.5 cm long theta pinch coil. The experimental results and their analysis have been reported (IEEE Plasma Sciences Meeting, 1977), Report C00-4020-4.
3. Analytical work has been completed to extend the usefulness of the Thomson scattering laser system in carrying out two new diagnostic measurements.

- a. By the use of Nd-Glass laser rods and new photodetectors, lower density plasmas can be diagnosed.
 - b. By the use of the ruby laser rods and new detector electronics, the flow velocity of the electrons being lost from the theta pinch column can be detected.
4. Study of the experimental generation of mirror fields at the end of the 50 cm long pinch has been initiated. Fields of 50 kG have been generated in an 8 cm long, 6 cm diam. solenoid that was driven by a 14 μ F, 18 kV supplementary capacitor bank. Single turn coils with rise time equal to the main bank have also been tested.
 5. Lagrangian one-dimensional (axial) time dependent code without thermal conduction has been tested and used successfully to model Scylla I-C behavior.
 6. A variety of simple implosion models have been used to predict post-implosion density and temperature. It has been found that snowplow models work reasonably well for collisional experiments but bounce models are not giving good results for Scylla IV-P.

Plans

1. Assembly of theta pinch facility with a 50 cm long coil being driven by a 240 μ F bank.
2. Fabrication, installation and testing of crowbar current on 50 cm theta pinch.
3. Installation of z-preionization system to enhance preionization and eliminate trapped fields.
4. With the 50 cm long pinch, without mirrors and without trapped flux, study of conditions at and near end with all diagnostics (Thomson scatter, spectroscopy, pressure, magnetic field, and electric field probes). High resolution transient ($\sim 0.1 \mu$ sec) measurements will be made. Primary emphasis will be placed on unique determination of electron conduction losses.
5. Continued development and testing of magnetic mirror field circuitry for 3:1 mirror fields. Initial study will generate 2:1 mirror fields with 7.5 cm O.D. discharge tube in 10.5 cm i.d. pinch coil reduced to 7.5 cm at ends. Subsequent work with add-on single turn coils driven by an external circuit and crowbarred to provide a total 3:1 mirror field.
6. Investigate effects of boundaries, un-ionized gas and magnetic field curvature on plasma flow in the exhaust region.

Milestones

Complete assembly and preliminary discharge testing of 50 cm long theta pinch with 240 μ F discharge apparatus—March 1978. This task has been delayed by detailed diagnostic measurements (e.g., Thomson scatter) for the 25 cm pinch that had not been anticipated. New milestone date—June 1978.

Project

The High Energy High Density Plasma Production Method

D. Y. Cheng, C. N. Chang, P. P. Tripathi

FY77 \$102.4K op FY78 \$110K op

Purpose

To study method of producing plasmas which are suitable for CTR applications.

Approach

Using a deflagration plasma gun to produce high energy ($>10^{14} \text{ cm}^{-3}$) collimated plasma column for CTR devices.

Progress

1. Cross field injected plasma into LLL 2 X II Mirror. Data show that plasma penetrates the magnetic field of strength 4 KG and can be trapped with the aid of target plasma.
2. Further study on the energy efficiency indicates that the efficiency is a linear function of the product of the square of the discharge current and the capacitance of the energy storage system, from which the method of obtaining the optimal efficiency for deflagration plasmas can be extrapolated.
3. Setting up and designing the experiments for injecting plasma into Microtor and SURMAC of UCLA as joint ventures.
4. Extended the duration of plasma production to 52 μs from 8 μs with 100 KJ energy storage system. The data indicate that there has no serious problem to extend plasma production duration up to several hundred microseconds.

Plans

1. Study the content of the plasma particles.
2. Measure the electron temperature.
3. Inject plasma into Microtor and SURMAC.
4. Further study of plasma injection into Beta-II at LLL.

Milestones

1. Deflagration gun plasma particle energy spectrum—September 1978.
2. Plasma cross field injection into Microtor—November 1978.
3. Plasma injection into SURMAC—December 1978
4. Electron temperature in the deflagration gun plasma—December 1978.
5. Plasma injection into Beta-II—May 1979.

Graduate Students (% DOE Support)

Salvatore LaPorto (50%)

Graduates

None

Other Professional Staff

None

Major Recent Publications

"Time History of Impurity Lines and Their Removal in a Coaxial Gun Plasma," Accepted for publication, IEEE Transaction of Plasma Science.

Project

Initial Phases of a Tokamak Discharge
Roger Bengtson
FY77 \$500K (two year funding)

Purpose

Characterize the initial 5-10 milliseconds of a tokamak discharge with primary attention on mechanisms by which atoms and molecules (hydrogen and impurities) are produced and upon their interactions with and transport in the heated plasma. Runaway electrons will also be studied to determine the conditions in which both runaway electrons and impurities in the plasma can be minimized.

Approach

A research tokamak with $B_T = 10 - 20$ kG, $R = 51$ cm, $r = 17$ cm, $n_e = 0.1 - 5 \times 10^{13} \text{ cm}^{-3}$ and usable test time of 50 msec will be used. The vacuum chamber will have four full length diagnostic windows, 34 cm long, 15 cm wide, and a tangential port. Diagnostics will include laser scattering, microwave interferometer, spectroscopic instrumentation and electric and magnetic probes. Auxilliary heating is planned to be provided using Alfvén waves.

Progress

Assembly of tokamak is complete. Initial testing on toroidal field has begun. Discharge cleaning in operation.

Plans

1. Begin operation of research tokamak.
2. Install diagnostics for runaway electrons and breakdown studies.
3. Initiate studies to evaluate initial phases of discharge formation and the effect of runaway electrons.
4. Install Alfvén wave heating.

Milestones

1. Complete installation and testing of diagnostics required for breakdown and runaway electron studies—October 1978.

2. Complete preliminary investigations to characterize and model the initial discharge formation—March 1979.
3. Complete investigations to characterize and model the initial discharge formation—September 1979.
4. Finish preliminary analysis of runaway electrons to determine their effects on discharge formation, impurity evolution, plasma confinement and heating—September 1979.

Graduate Students (% DOE support)

J. Benesch (100), D. Blejer (100), S. Eckstrand (100), R. Gandy (100), S. Lin (100), S. McCool (100), D. Pease (100), D. Thomas (100)

Other Professional Staff

Dr. P. Phillips

Major Recent Publications

"Design of the PRETEXT Tokamak," J. F. Benesch, R. D. Bengtson, S. A. Eckstrand, K. W. Gentle, S. H. Lin and P. Wildi, FRCR #153, May 1978. Presented at the Small Toroidal Plasma Users Meeting, IEEE meeting, Monterrey, California.

Project

Confinement

D. W. Kerst, R. S. Post, S. C. Prager, J. C. Sprott
FY77 \$235K op (two year funding)

Purpose

To study basic physics of confinement, transport and stability.

Approaches

Tokapole:

A 4 node poloidal divertor Tokamak configuration is created by positioning of octupole rings for dee, inverse dee or square configurations.

Levitated Octupole:

Gun and ohmic heated plasmas are used to obtain a wide range of mean free paths (over four orders of magnitude) and finite β . Fluctuation spectra are measured by probes and microwave scattering. Confinement studied by measurement of plasma profile evolution.

Progress

Tokapole:

1. Square and both dee equilibrium obtained. Flux plots and constant current contours measured;
2. Detailed spectroscopic studies have measured selective line intensities of impurity radiation. Cleaning continues.

Levitated Octupole Examined:

1. Effect of supports on T^* , the effective temperature of the vortex spectrum;
2. Effect of shear on vortex diffusion on a collisional plasma;
3. Correlation of low frequency fluctuations with diffusion in the absolute min B region;
4. D.C. and A.C. ohmic heated plasmas generated with $n \sim 3 \times 10^{12} \text{ cm}^{-3}$, $T_e \sim 30 \text{ eV}$, $T_i \sim 10 \text{ eV}$, without levitation or discharge cleaning;
5. Ware pinch effect observed close to theory;
6. Coherent fluctuation in trapped ion region, in both good and bad curvature regions.

Plans

Tokapole:

1. Compare dee, inverse dee, and square stability;
2. Use ECRH preionization or a pre-existing octupole field for center breakdown and study runaway production and discharge evolution;
3. Use gun injected plasma ($n \sim 10^{11} \text{ cm}^{-3}$) in Tokamak configuration to study collisionless plasma phenomena (e.g. trapped particle instabilities).

Levitated Octupole:

1. Install microwave scattering apparatus;
2. Optimize A.C. ohmic heating for high β effects on MHD stability and finite β effects on microstability and transport.

Milestones

Tokapole:

1. Compare MHD stability of dee, inverse dee and square—January 1979;
2. Feasibility of using gun injected plasma for collisionless plasma studies—January 1979.

Levitated Octupole:

1. Ware pinch experiment completed (calculate profile evolution for data comparison and study collisional plasma without trapped particles)—January 1979;
2. Identify instability in trapped ion region—July 1979;
3. Obtain finite β ($> 1\%$) effects on microinstability—January 1979;
4. Examine β limit on MHD stability—June 1979.

Graduate Students (% DOE support)

D. D. Brochous (100%), A. Erhardt (25%), H. Garner (100%), R. Groebner (100%), B. Lipschultz (100%), H. Matsumoto (100%), T. Osborne (44%), M. Phillips (100%), E. Rose (100%), J. Twitchell (100%), M. Zarnstorff (100%), J. Halle (100%).

Graduates

C. Armentrout (1977), T. Casper (1978), J. Rudmin (1974), A. Cavallo (1975), J. Greenwood (1975), G. Schmidt (1975), A. Navratil (1976).

Other Professional Staff

Prof. Richard Dexter

Major Recent Publications

1. Diffusion Coefficient Scaling in a $\epsilon \rightarrow 1$ Plasma, G. Navratil and R. S. Post, *Physics Fluids*, **20**, 1207 (77).
2. Observation of Classical Diffusion in the Presence of Large Amplitude Density Fluctuations, G. Navratil and R. S. Post, *Phys. Letters A*, **64A**, 1978.

Project

Divertor Simulation Studies

J. C. Sprott, G. A. Emmert, D. W. Kerst
FY77 \$80K op (two year funding)

Purpose

To test theoretical models of plasma behavior in the scrape-off zone of a divertor, and to test poloidal magnetic and $\vec{E} \times \vec{B}$ divertor behavior in octupoles and tokapoles.

Approach

A limiter was installed in the dc machine to produce a scrape-off zone. A biasable poloidal magnetic divertor was installed in the levitated octupole. The Tokapole II is operated in a four-node poloidal divertor configuration.

Progress

1. Density and potential profiles have been measured on open field lines in the dc machine.
2. Density, potential, and particle flux have been measured in the vicinity of the $\vec{E} \times \vec{B}$ poloidal divertor in the levitated octupole.
3. A four-node poloidal divertor configuration has been achieved in Tokapole II.
4. Installation of divertor plate in Tokapole II in August 1978.

Plans

1. Measure transport on open field lines in the dc machine.
2. Study effects of divertor plate on density profiles in Tokapole II.
3. Diagnosis of combined electric and magnetic divertor action with poloidal divertor in the levitated octupole.

Milestones

1. Measure flux to divertor plate on open field lines in dc machine—December 1978.
2. Completion of $\vec{E} \times \vec{B}$ divertor measurements—April 1979.

Graduate Students (% DOE support)

Clifford Strawitch, 100%; Edward Strait, 100%

Graduates

Roger Richards, 1976

Other Professional Staff

None

Major Recent Publications

1. Experimental Demonstration of $\vec{E} \times \vec{B}$ Plasma Divertor, E. J. Strait, D. W. Kerst, J. C. Sprott, accepted for publication in Physics of Fluids.

PLASMA HEATING (PH) PROGRAM

The function of the Plasma Heating Program is to study the physics and performance of auxiliary methods to heat fusion plasmas.

The program in plasma heating has two parts. The first deals with the development of negative ion sources for neutral beams. These will be required for high energy beams at greater than 100 kev. In addition, positive ion sources with significantly greater efficiency than conventional sources are also being studied. The second part involves rf heating techniques. The program involves several sites and covers the entire range of rf methods, i.e., ion cyclotron, lower hybrid and electron cyclotron heating methods. The heating program is intended to provide the physics basis for rf as an auxiliary heating mechanism.

Progress—Plasma Heating

- The construction of a 150 kW, 35 GHz, 10 msec gyrotron by NRL has been completed. This will be used for electron cyclotron resonance heating (ECRH) profile control and preionization on Microtor, ISX-B, and Versator II.
- Experimental evaluation of optimal antenna designs for ion cyclotron resonance heating (ICRH) has been accomplished on Microtor at UCLA. These results will be utilized in constructing five 1 MW sources to be used on Macrotor.
- Upgrading of the Versator II magnetic field to 15 kG was completed at MIT. The vacuum vessel was also modified so that a 200 kW lower hybrid experiment using a 4 grill waveguide can be done. In addition the NRL gyrotron will be accommodated next year for studies of ECRH.
- Fabrication of the Tokapole II device at Wisconsin was completed and operations initiated. A 2 MW ICRH experiment is one of its primary purposes.
- The noise characteristics of a cylindrical Dimov magnetron discharge for producing D^- were studied. The noise level was found to be extremely high and would severely inhibit the focusing of a D^- beam (MIT).

Project

L-3, L-4: Plasma Heating and Nonlinear Wave Studies

K. L. Wong, M. Ono

FY77 \$300K op	FY78 \$260K op
0 eq	15 K eq

Purpose

To study both linear and nonlinear wave behavior in plasmas, with special attention to nonlinear lower-hybrid wave phenomena (L-3) and parametric instabilities near the ion-cyclotron frequency (L-4). RF heating in toroidal plasmas will be studied in the new steady state torus (T-1) which is the replacement for L-4.

Approach

A tungsten filament source is used to produce a quiet plasma suitable for wave studies. Plasma waves are detected by probes connected to rf interferometers, spectrum analyzers and boxcar integrators. In L-3, the lower hybrid waves are excited by a multiple-ring slow-wave structure which can be operated at 1 kW power level. In L-4, a Faraday shielded inductive coupling structure excites large amplitude electromagnetic fields at frequencies near the ion-cyclotron frequency. This coupling structure is driven by a 3 kW oscillator operating in the 2-4 MHz range. The plasma in T-1 will be produced by RF techniques including 5 kW lower hybrid waves at 75 MHz, 5 kW whistler waves at 2.45 GHz and 10 kW electron cyclotron resonance heating at 10 GHz.

L-3:

Progress

1. The investigation of resonant decay of lower hybrid waves has been completed. Parametric decay due to $E_{o\parallel}$ and $\bar{E}_{o\perp} \times \bar{B}$ coupling has been observed. Coupling due to $E_{o\parallel}$ can be important at low plasma densities. Because of convective loss in the finite extent pump field, the threshold for parametric decay is considerably higher than the collisional threshold for $\bar{E} \times \bar{B}$ coupling. Since the energy in the sideband can exceed 10% of the pump wave energy and since the parallel wavelength of the sideband is considerably shorter than that of the pump wave, some pump depletion and enhanced Landau heating of electrons have been observed during the parametric decay process.
2. Due to the current interest in steady state tokamaks, an experiment on current generation by electron plasma waves was done on L-3. Unidirectional waves were launched by a 20 cm long slow wave structure consisting of eight rings with 90° phase difference between adjacent rings. 80% of the wave energy propagates at the preferred direction and generates a current in the plasma. The magnitude of the current can be estimated from momentum conservation in the wave-particle interaction process.

3. The RF system is being upgraded to high power level (1 kW cw) to study the nonlinear propagation of lower hybrid waves. The RF source and the properly phased power divider has been completed. The high power slow wave structure is being constructed.

Plans

1. The 1 kW RF system will be completed for nonlinear lower hybrid wave propagation studies.
2. The lower hybrid wave coupling efficiency, ponderomotive force effects and particle trapping effects will be investigated.

Milestones

1. Complete the 1 kW RF system—January 1979.
2. Understand the ponderomotive force effect on the propagation and coupling efficiency of lower hybrid waves—September 1979.

L-4:

Progress

1. Parametric excitation of drift waves in a two-ion species plasma (He and Ne) has been observed in the frequency range $\omega_o \approx (1.3 - 1.6)\Omega_{He}$ for a wide range of ion concentration ratio. The dispersion relation of drift waves in a two-ion species plasma has been measured and shown to agree well with theory. The parametric coupling mechanism of the decay has been verified by observing the threshold behavior in the magnetic field and the ion concentration ratio parameter space. The measured decay threshold is in good agreement with theory.
2. L-4 will be converted into a steady state torus named T-1 in December 1978. The design of T-1 has been completed and the construction has begun. The vacuum pumps and the toroidal vacuum chamber have been ordered. The supporting structure for the field coils and the lead shielding are being fabricated.

Plans

1. To convert the linear machine, L-4, into the toroidal machine, T-1.
2. To develop a quiescent plasma source for T-1.
3. To investigate lower hybrid wave heating and the current generation by unidirectional lower hybrid waves.
4. To investigate ion cyclotron heating in a toroidal plasma.

Milestones

1. Complete the construction of T-1—January 1979.
2. Develop a quiescent plasma source for T-1—April 1979.
3. Complete the construction of the wave antenna and start experiments on lower hybrid waves and ion cyclotron waves—August 1979.

L-3, L-4:

Graduate Students

1. Project students (% DOE support; degree, years to complete) James R. Wilson (100, PhD, 2).
2. Graduated during past three years (year, employed in fusion): Boris Grek (1975, yes); Paul Bellan (1975, yes), Masayuki Ono (1978, yes).

Project

ECRH with a Gyrotron Oscillator
Victor L. Granatstein
FY77 \$60 op FY78 \$225K op

Purpose

Design, build and test a 200 kW, 10 ms, 35 GHz gyromonotron oscillator, then use this device in joint experiments on electron cyclotron heating on Tokamaks.

Approaches

1. Extend the theory and designs for a short pulse gyrotron oscillator developed with DoD funding to build a 200 kW 10 ms oscillator with a frequency of 35 GHz.
2. Design and fabricate systems for the linear polarization and transmission of the radiation. It is expected that approximately 125 to 175 kW will be injected into a given Tokamak.
3. Use the oscillator on several Tokamaks to test theories of electron cyclotron heating. The Tokamaks proposed are:
 - a. Microtor, at UCLA. This small Tokamak will allow the determination (and solution) of technical problems associated with the coupling of the two devices. Its parameters allow the study of single pass absorption of extraordinary waves, and multipass absorption of ordinary waves. The gyrotron output will be linearly polarized to allow the separation of these two mechanisms.
 - b. ISX-B, at ORNL. This larger Tokamak will allow the study of ECH in a high temperature (>1 Kev) plasma, where significant single pass absorption is predicted for either mode. Bulk heating will be marginal but measurable with the present gyrotron power and pulse length. Studies will concentrate on preionization and profile control. The Varian 28 GHz CW gyrotron may be available simultaneously, and the effect of two sources at different frequencies could be studied. As in the Microtor experiments, the NRL gyrotron output will be linearly polarized, allowing the separation and identification of the effects of extraordinary and ordinary waves. A full complement of Tokamak diagnostics will be available.
 - c. Versator II, at MIT. This machine is suited for long term detailed experiments on ECH, due to its accessibility and design. The large vacuum ports will allow easy injection of the microwave power. The ohmic heating and gyrotron powers will be roughly equal, so significant bulk heating is expected. It is expected that experiments on this machine will address in detail questions raised but not answered, on previous experiments.

Progress

The gyrotron is presently being tested in the long pulse mode. The oscillator in the short pulse mode produced 90 kW. In order to reach the desired 200 kW, optimization of the power output will continue in parallel with the ECH studies. Designs and testing of components for the experiments on Microtor are in progress. Discussions of preparations necessary for the experiments on ISX-B have been initiated.

Plans

Perform ECH experiments on the following Tokamaks.

1. Microtor, at UCLA
2. ISX-B, at ORNL
3. Versator II, at MIT

Milestones

Tests on the long pulse oscillator completed on 1 August 1978.

1. Begin experiments on Microtor—1 September 1978.
2. Complete experiments on Microtor—December 1978.
3. Begin experiments on ISX-B—February 1979.
4. Complete experiments on ISX-B—May 1979.
5. Begin experiments on Versator II—July 1979.

Graduate Students

None

Graduates

None

Other Professional Staff

Dr. Kwo Ray Chu

Major Recent Publications

None

Project

Wave Heating and Diagnostics for Fusion Plasmas

R. W. Gould

FY77 \$490K

FY78 \$1.5K

Purpose

Investigate radiofrequency and microwave interactions with plasmas as they apply to heating and diagnostics of low beta toroidal plasmas.

Approach

Experimental and theoretical studies of wave launching, mode structure, and energy deposition mechanisms in the ion cyclotron range of frequencies are conducted. Plasma turbulence in the 0-500 kHz range is studied with electric and magnetic probes. A research tokamak with $R = 45$ cm, $a = 15$ cm, $B_T < 10$ kG is the main experimental facility for these investigations.

Progress

1. Fast magnetosonic eigenmodes in the 6-20 MHz range ($f_{ci} = 6$ MHz) have been observed in transmission and reflection. The complex input impedance of a two turn loop antenna has been measured as a function of density for various frequencies at the 100-300 watt level. Considerable care was necessary in the design of both the antenna and the impedance matching network to minimize their resistance in relation to the "radiation" resistance of eigenmode resonances. "Radiation" resistances of 3-4 times the intrinsic antenna resistance were found, thus implying that 75-80% of the power was coupled into a toroidal eigenmode.
2. Electrostatic turbulence spectra and cross-correlation functions from two spatially separated and movable electrostatic probes show fluctuations in the 5-200 kHz range which propagate poloidally in the ion-diamagnetic direction, with correlation lengths of 5-10 cm and $\delta n/n \sim .3$. The spectra consists of a general background which roughly decreases with increasing frequency, as found in other tokamaks. Superimposed on this background is a series of maxima which seem to correspond to poloidal modes ($m = 2 \dots 8$).

Plans

1. A study of magnetic field fluctuation spectral and cross-correlation characteristics will be conducted with spatially separated and movable magnetic probes. The relation of the magnetic to the electrostatic fluctuations previously observed will be studied. The overall objective is to contribute to the understanding of anomalous electron transport across the magnetic field.

2. The plasma density in the Caltech tokamak has been found to decay by a factor of about 5 following the initial plasma formation. Programmed gas puffing has been installed in order to maintain and raise the plasma density. This is especially important for magnetosonic mode heating experiments, where the mode frequency is density dependent and the antenna and associated matching network have a high Q.
3. A 5-30 MHz, 50 kilowatt, pulsed amplifier is being prepared for ICRF heating experiments. This power is greater than the ohmic heating power and substantially greater than the power to the ions from collisions.

Milestones

1. Report on magnetic fluctuations—December 1978.
2. Report on ICRF heating experiments—April 1979.

Graduate Students (% DOE Support)

B. Levine (100%), M. Hedemann (100%), G. Greene (100%)

Graduates

C. Grabbe (1978), R. Kubena (1978), D. Hwang (1978)

Other Professional Staff

P. Bellan (15%)

Major Recent Publications

C. L. Grabbe "Resonance Cores and Mode Conversion in a Warm Magnetized Plasma" (PhD Thesis)

R. Kubena "Fluctuations in a Tokamak Plasma" (PhD Thesis)

D. Hwang "Propagation of Fast Magnetosonic Modes in a Tokamak Plasma" (PhD Thesis)

B. Levine, G. Greene, R. Gould "Focusing Resonance Cones" Phys. Fluids 21, 1116 (1978)

C. L. Grabbe, "Resonance Cones in a Warm Bounded Plasma," Phys. Fluids 20, 599 (1977)

Project

Study of Hot Plasma Transport and Heating in Micro/Macrotror

K. MacKenzie, R. J. Taylor

FY77 \$ 0 op FY78 \$425K op
180K eq

Purpose

To study RF heating at resonant and non-resonant modes and to compare the prospects of ICRF, ECRF and LH schemes. To increase beta and to study diffusion in the presence of heating.

Approach

Two tokamaks have been installed and are operating now from common power supplies. It is possible to put in up to 5 MW of ICRF in Macrotror once a favorable module (1 MW) is developed.

Progress

1. 40 kW of RF power has been delivered to Macrotror (limited by arcing).
2. Made observation on the generation of fast neutrals.
3. The impurity influx is observed to increase and the density to decrease due to RF.
4. Increased ICRF to 200 kW in August 1978.

Plans

1. To increase ICRF power input to 200 kW first, from 40 kW, and then to 1 MW per port. Up to 5 ports could then be committed to heating.
2. To try ECRF in Macrotror (N. Luhmann) and Microtror (NRL) and compare the results to ICRF.
3. To set up high power antennae for Microtror and to apply ICRF there also.
4. Suppression of impurities during RF heating by cold electron injection.

Milestones

Apply 100-200 kW of ICRF to Macrotron—October 1978.

Graduate Students (% DOE support)

David Whelan (100% summer, 50% academic year); Curtis Menyuk (100% summer)

Graduates

None

Other Professional Staff

L. Oren	S. Talmadge
G. Morales	J. Carter
S. Zweben	

Major Recent Publications

R. J. Taylor and G. J. Morales, *ICRF Heating Studies in the Macrotron Tokamak* (an invited paper presented at the Int'l Symposium on Heating in Toroidal Plasmas, held in Grenoble, France).

Project

Neutral Beam Research—Negative Ion Sources

L. D. Smullin

FY77 \$0 op
0 eq

FY78 \$40K op
0 eq

Purpose

Study of discharge characteristics of magnetron-type surface ionization and negative ion sources.

Approach

Detailed measurements are being made of the terminal (V-I) characteristics of the primary discharge and of the plasma parameters deduced from probe measurements. A simple, circular cross-section, co-axial device has been shown to have properties nearly identical to the planar magnetron geometry now used for ion sources.

Progress

In the co-axial magnetron geometry ($r_{\text{cath}} = 1.25$ cm, gap = .32 cm) we have observed V-I patterns similar to those reported for ion sources. The discharge is very noisy—40% to 100% modulated. The time average voltage is ~ 400 v for an H_2 discharge and about 200 v for an H_2 -Cs discharge for 5-10 kw discharges (600 μsec pulses, ~ 2 sec repetition time). Time averaged probe measurements indicate $10^{11} < n_e < 10^{13}$, $8 < T_e < 16$ ev, with $4 < VI < 13$ kw. The density $n_e(r)$ and the plasma potential $\phi_p(r)$ have been measured, showing rapid changes near the cathode and relatively constant behavior in the rest of the gap. The probe theory has been extended to account for presence of negative ions, and we estimate that $n_{\text{H}^-} \rightarrow 1/2 n_e$ with Cs in the discharge.

The noise spectrum of the cylindrical magnetron has been measured and is relatively flat from ~ 1 MHz to ~ 200 MHz, with a strong component in the range 1.5–2 GHz. The spectrum is the same whether taken from a photomultiplier, a probe, or the cathode terminal. The noise level drops rapidly as $\omega_{ce}\tau_{\text{col}}$ is reduced. Nearly identical results were obtained on an ion source provided by K. Prelec of Brookhaven National Laboratory.

Plans

The project will concentrate on the study of the noise mechanism(s?). A simple ion extractor will tell how much noise is carried by the H^- beam. Two-probe correlation measurements will give an indication of $k(\omega)$. Linear instability theory for a magnetized plasma ($\omega_{ce}\tau \approx 2$) will be studied with an applied $\vec{E}_0 \perp \vec{B}_0$. The first model will assume a step profile in $\vec{E}_{r0}$ resulting in a drifting stream near the cathode slipping against a stationary plasma (where $\vec{E}_{r0} = 0$) near the anode.

Milestones

Probe correlation measurements $k(\omega)$ will be under way—November 1978.

First numerical results of the linear dispersion theory—December 1978.

Noise measurements on extracted H^- ions—January 1979.

Graduate Students (% DOE support)

Peter Kenyon (100%)

Graduates

None

Other Professional Staff

None

Major Recent Publications

Submitted to JAP: "Gas Discharges in Planar Low Pressure Thermionic Diodes," Parts I & II; "Theoretical Model of the Berkeley Multifilament Positive Ion Source," by L. Bromberg and L. D. Smullin.

Project

Tokamak Research on Versator II

George Bekefi

FY77 \$265K op FY78 \$425K op
17K eq

Purpose

To study RF heating of Tokamak Discharges at the lower hybrid frequency and at the electron cyclotron frequency.

Approaches

1. RF power of 200 kW having a frequency of 800 MHz will be injected into the tokamak discharge via four waveguide grills phased 0, 180°, 0, 180°.
2. RF power of 200 kW having a frequency of 35 GHz will be injected into the tokamak near the gyrofrequency and the second harmonic. Injection will be attempted both radially inwards and radially outwards.

Progress

1. The Versator II tokamak went on the air May 1, 1977 and was operated with good equilibrium at a toroidal magnetic field of 8 kG.
2. The machine has been upgraded to operate at 15 kG levels and the vacuum chamber has been modified to accept the 12 cm wide waveguide grill.
3. Charge exchange diagnostics, Thomson scattering, soft x-ray, synchrotron radiation, and 4 mm interferometry have been completed.

Plans

1. To begin, September 1, 1978, detailed studies of rf propagation and of heating at the lower hybrid frequency.
2. To begin, May 1, 1979, similar studies in the electron cyclotron frequency regime.

Milestones

See above.

Graduate Students

Alan S. Fisher (50%), Kirk E. Hackett (0%), Stephen Knowlton (0%), Ana Luisa Laffes (0%), Calvin W. Lowe (0%), Burton Richards (100%), Robert L. Smith (0%), David S. Stone (100%)

Graduates

None

Other Professional Staff

Ady Hershcovitch, Post-doctoral Fellow (left July 1, 1978)

Major Recent Publications

None

Lower-Hybrid R. F. Heating of Versator II

M. Porkolab

FY77	0 eq	FY78	\$15,200 op
			15,800

Purpose

To study the physics of rf heating of tokamak discharges at the lower-hybrid frequency

Approach

A maximum of 200kW, 10msec long pulsed power at 800 MHz will be injected through a four-wave-guide grill phased $0\pi, 0\pi$. In addition, a six-waveguide grill will also be constructed in 1979.

Progress

The installation of the high-power rf equipment and grill has been completed. The necessary theoretical work for the waveguide design has been carried out. Construction of rf probes and bolometers have been completed. A feasibility study of rf generated dc current has been completed.

Plans and Milestones

1. To determine the efficiency of coupling with a four-waveguide grill—December 15, 1978.
2. To measure the penetration of the pump wave, and to measure the wavelengths of the parametric decay waves around the torus—March 15, 1979.
3. To measure the heating efficiency of ions, electrons, and to obtain power balance—August 15, 1979.
4. To determine the heating mechanism(s)—October 1, 1979.
5. To study the feasibility of dc current generation by launching a unidirectional lower-hybrid wave.

Graduate Students (% DOE support)

Stephen Knowlton, 0%; Calvin W. Lowe, 0%; Robert L. Smith, 0%

Graduates (Year)

None

Other Professional Staff

None

Major Recent Publications

None

Project

Heating

J. C. Sprott, J. E. Scharer

FY77 \$425K op FY78 0 op

Purpose

To investigate ECRH, ICRH, LHRH, and ohmic heating of toroidally confined plasmas.

Approach

A levitated toroidal octupole and a smaller octupole with embedded toroidal discharge (Tokapole) are used to generate target plasmas for heating studies.

Progress

1. A new experimental device (Tokapole II) has been constructed.
2. A 2 MW ICRH oscillator has been developed and tested.
3. Fast magnetosonic wave eigenmodes have been observed and studied.
4. 20 kW of lower hybrid heating has been applied to the octupole resulting in a ΔT_i of 14 eV.
5. Installed 2 MW ICRH oscillator on Tokapole II.

Plans

1. Produce hot ion plasmas in Tokapole II with ICRH.
2. Study effectiveness of ECRH breakdown of Tokamak discharges.
3. Increase lower hybrid power and study heating mechanisms on the levitated octupole.
4. Hot ion gun injection into levitated octupole.
5. Ohmic heating in levitated octupole.

Milestones

1. Determine effectiveness of ECRH preionization of Tokamaks—November 1978.
2. Achieve hot ion plasmas with ICRH in Tokapole II—February 1979.
3. Increase lower hybrid power to 100 kW and identify heating mechanisms—May 1979.

Graduate Students (% DOE support)

P. Smith (100%), D. Holly (100%), A. Biddle (100%), D. Witherspoon (100%), K. Miller (100%), T. Owens (100%).

Graduates (year)

K. Wong (1975), R. Breun (1975), R. Raymond (1975), R. O'Doherty (1976), W. Guss (1976), J. Barter (1976), J. Etzweiler (1977).

Other Professional Staff

None

Major Recent Publications

1. Measurements of Electron Cyclotron Heating Rates, J. D. Barter, J. C. Sprott and K. L. Wong, Phys. Fluids 17, 810 (1974).
2. Ion Cyclotron Heating in the Wisconsin Toroidal Octupole, J. D. Barter and J. C. Sprott, Plasma Physics 19, 945 (1977).

MEASUREMENTS AND INSTRUMENTATION (MI) PROGRAM

The Measurements and Instrumentation Program has three functions. These are: to provide advanced diagnostic techniques for the measurement of parameters not currently directly detectable, e.g., current density; to develop and upgrade instrumentation for more sophisticated measurements, e.g., spatial and temporal resolution; and to standardize the instrumentation and techniques so that advanced diagnostics become routine.

The new generation of larger hotter confinement devices has rendered some diagnostics obsolete, e.g., ion temperature measurements through charge exchange. New diagnostics were required and found. However, there are still some parameters which cannot be measured directly. The most important of these parameters is current density.

Recent advances in such areas as spectroscopic instrumentation and lasers have made possible much better spatial and temporal resolution of a number of parameters. Higher resolution instruments and the deployment of arrays of detectors for imaging offer the promise of improved accuracy.

The ultimate goal of such a program must be the adoption of a standardized diagnostic and instrumentation package along with data processing methods. This would permit the rapid and unambiguous comparison and contrasting of data from machine to machine.

Progress—Measurements and Instrumentation

- A vertical asymmetry in impurity distribution was observed in Alcator A by soft x-ray and EUV spectroscopy measurements. This unequal distribution is attributed to gradient B curvature drifts. In addition, $Z_{\text{eff}} \sim 1$ was measured (Johns Hopkins).
- Studies of the neutral beam driven mirror device, 2X-IIB, have determined the impurity concentrations, probable sources, and the fraction of input power lost by oxygen line radiation. Spatially resolved UV measurements on EBT have determined impurity concentrations in both the toroidal core and blanket plasmas (Johns Hopkins).
- Using tunable dye laser radiation which is first doubled, then tripled, low power output of Lyman- α radiation was obtained. When higher powers are obtained this laser source will be used to determine neutral density (Maryland).
- A far infrared receiver suitable for ion temperature measurements by laser scattering was developed. The receiver was also successfully used for narrow-band synchrotron emission measurements on Microtor (UCLA).
- Broadband x-ray spectra were used to analyze emission from Alcator A and Constance I. A method of observing and monitoring disruptions was also developed. The techniques are forerunners of a 2-dimensional x-ray imaging system currently being constructed for Alcator C and being studied for TMX (AS&E).

**Experimental Plasma Research
LASL**

Category MI

Project

Automated Data Acquisition of Two-Dimensional Diagnostics

F. C. Jahoda

FY77	\$200K op	FY78	\$58K op
	45K eq		10K eq

Purpose

Automated data acquisition of two-dimensional data formats, e.g., streak camera pictures, interferograms, space resolved Thomson scattering.

Approach(es)

Acquisition of signals in format amenable to automated digitization followed by digital computer processing.

Progress

Procurement, debugging, and interfacing to Sigma 2 computer of digital TV frame grabber. Improvement of s/n of spatially resolved Thomson scattering apparatus by factor 4, by expansion to 10,000 pixel read-out for 600 space/wavelength channels.

Plans

Completion of frame grabber, Thomson scattering projects to routine usage on major experiments. (Expansion of project to "Diagnostic Development" with initial emphasis on Faraday Rotation of Far Infrared Laser (119 micron) for ZT-40).

Milestones

Further progress in pursuance of plans outlined above.

Graduate Students

None

Graduates

None

Other Professional Staff

K. A. Klare (part-time), K. B. Freese (part-time)

Major Recent Publications

None

Fast Neutron Diagnostics for Advanced Thermonuclear Experiments

FY77 \$40K op FY78 \$100K op
10K eq

To review and evaluate existing techniques for fast neutron diagnostics in advanced thermonuclear experiments where increased density, temperature, and size limit active and passive particle probing. Also, to recommend modifications and select promising new techniques for further development.

The characteristics of recoil proton detectors, fission chambers, and ^3He gas counters will be evaluated with regard to efficiency, neutron energy resolution, time resolution, count rate capabilities, minimum data acquisition time and response to intense magnetic fields and photon fluxes. Promising systems will be assessed with regard to their performance in the measurement of plasma parameters under the conditions of a fusion experiment.

1. A high sensitivity, wide dynamic range neutron activation detector has been developed and calibrated for short pulses of D(d,n) and T(d,n) sources.
2. A photomultiplier tube base has been developed for use at count rates up to 10^7 cps. Commercially available electronics for neutron-gamma discrimination and linear amplification have been found to be viable up to 5×10^5 cps and neutron spectra have been obtained during a 1 sec source pulse at that count rate.
3. A simple collimator has been designed and characterized. It provides 2-3 mm spatial resolution at $2\frac{1}{2}$ meters for 14-MeV neutrons.
4. Several stilbene and NE 213 recoil proton spectrometers and one ^3He ionization chamber have been characterized with regard to efficiency, neutron energy resolution, and count rate capabilities.
5. The spectrum of neutrons generated in the TFTR plasma has been calculated under a variety of conditions and the results are being used to model the performance of various neutron detection systems used to measure plasma parameters.

Plans

1. Investigate various gas, liquid, and solid scintillation detectors with neutron energy thresholds in the 1-14 MeV range.
2. Investigate the energy resolution and count rate capabilities of various ^3He proportional counters.
3. Investigate, using very simple calculations, the effects of collimation and attenuation on the performance of several neutron diagnostic systems.
4. Establish minimum performance characteristics required in order to reliably determine plasma parameters from neutron energy or yield information.
5. Evaluate the performance of one or two promising systems in a fusion experiment environment.

Milestones

1. Characterize various ^3He proportional counter systems with regard to efficiency, energy resolution and count rate capabilities—September 1978.
2. Complete initial estimates of the impact on performance due to collimation and attenuation—January 1979.
3. Complete initial investigation of scintillation detectors with neutron energy thresholds in the 1-14 MeV energy range—February 1979.
4. Establish minimum performance characteristics required to determine Z_{eff} and ion temperature on TFTR—February 1979.
5. Evaluate the performance of one promising diagnostic system in the environment of a fusion experiment—October 1979.

Graduate Students

None

Graduates

None

Other Professional Staff

None

Major Recent Publications

Dennis R. Slaughter and W. L. Pickles, "A Highly Sensitive Silver-Activation Detector for Pulsed Neutron Sources," (UCRL-81137) submitted to Nuclear Instruments and Methods.

Dennis R. Slaughter, "Plasma Neutron Diagnostic Techniques with Good Spatial and Energy Resolution," accepted for the IEEE Nuclear Science Symposium, October 1978, Washington, DC.

Project

Si-Diode Array Detector for Crystal Spectrometer
M. Gottlieb, S. von Goeler, I. Lowrance
FY78 \$30K op

Purpose

To develop large area array-detector to be used on x-ray crystal spectrometers for x-ray spectroscopy and ion temperature measurements.

Approaches

1. Experiments with 1 dimensional self-scanning Si-diode arrays.
2. Experiments with 2 dimensional CCD's operated as a line array by adding the charge in one dimension before the readout.

Progress

Two self-scanning arrays from Reticon, and electronics have been ordered. Negotiation with Texas Instruments on a 328 x 488 CCD development are in the final stage. Amplifiers and readout electronics are under construction.

Plans

To get both detector systems working, compare noise performance and speed, and to incorporate detectors in crystal spectrometer.

Milestones

1. Complete and check out Si-diode array by February, 1979.
2. Complete and check out CCD system by August, 1979. (This is contingent on a development at TI involving financial support from other parties.)

Graduate Students

None

Graduates

None

Other Professional Staff

G. Renda

Major Recent Publications

None

Project

Diagnostics of High Temperature Plasmas

C. F. Barnett, D. P. Hutchinson, J. A. Ray, P. A. Staats, K. L. Vander Sluis

FY77 \$175K op FY78 \$370K op
50K eq 75K eq

Purpose

Develop diagnostic techniques for the next generation of plasma experiments where increased density, temperature, and size will limit active and passive probing techniques.

Approach

Use of submillimeter lasers to measure (1) the spatial ion temperature of a tokamak plasma by Thomson scattering; (2) electron density by interferometric techniques; and (3) current density profile in a tokamak plasma utilizing Faraday rotation of a linearly polarized, modulated beam. A new approach to ion temperature measurements will be made using a liquid oxygen cell to measure D-D neutron transmission.

Progress

1. Pulsed powers of 1.2 MW for the 385- μ m line of D₂O have been achieved with a pulse length of 100 ns and a full width at the 1/e point of less than 25 MHz. The laser appeared to be operating in a pure Raman single mode.
2. Preliminary measurements were made of the Faraday rotation of a 393- μ m, cw, HCOOH laser beam projected across the ISX-A plasma. The system has been redesigned for future measurements.
3. Preliminary measurements were made on ISX-A of the transmission of D-D neutrons through a liquid O₂ cell for determining plasma ion temperatures.
4. An absolute calibration of a secondary emission H⁰ detector has been completed for 30-2500-eV H⁰ using a photodetachment of H⁻ technique.
5. Three neutral particle analyzers used on ORMAK and ISX-A were calibrated.

Plans

1. Measure current distribution of RPI small tokamak and ISX-B using Faraday rotation of HCOOH laser beam.

2. Increase output power of D_2O Thomson scattering laser by increasing the coupling between the CO_2 pump line and D_2O absorption line and install apparatus on ISX-B.
3. Measure the neutron total cross section resonance shape of O_2 more precisely and design a liquid oxygen cell for ion temperature measurements.
4. Develop a neutral particle spectrometer for low-energy (10-200 eV) neutral particles escaping the periphery of a tokamak plasma.
5. Measure narrow band synchrotron radiation from ISX-B.

Milestones

1. Measure Faraday rotation on RPI tokamak—November 1978.
2. Install Faraday rotation and interferometer on ISX-B—December 1978.
3. Install Thomson scattering laser on ISX-B—January 1979.
4. Measure narrow band synchrotron radiation using local oscillators with submillimeter laser—January 1979.
5. Develop low energy (10-200 eV) neutral particle analyzer—March 1979.
6. Complete measurement of neutron absorption cross section in O_2 and design ion temperature measuring apparatus—June 1979.

Graduate Students

None

Graduates

None

Other Professional Staff

C. H. Ma

Major Recent Publications

C. H. Ma, D. P. Hutchinson, and K. L. Vander Sluis, "A Modulated Submillimeter-Laser Polarimeter for the Measurement of the Faraday Rotation by a Plasma," submitted to Appl. Phys. Lett.

Project

FIR Laser Development

D. T. Hodges

FY77	\$58.2K op	FY78	\$120K op
	0 eq		5K eq

Purpose

Develop cw FIR laser sources for application to the diagnostics of thermonuclear plasmas.

Approaches

1. Optimize existing laser sources to achieve maximum cw output.
2. Delineate key mechanisms limiting efficiency of optically pumped lasers.
3. Develop new laser systems capable of 0.1-1.0 Watt emission level.

Progress

1. Development of quasi-cw laser operation at the 1-2 Watt level (100 μ sec FWHM) at 119, 447, 496 μ m.
2. Evaluation of hybrid output coupling techniques for optically pumped lasers.
3. Evaluation of 782.2 GHz line of CD₃Cl as potential local oscillator for pulsed D₂O laser.

Plans

1. Assemble probe and local oscillator quality 0.1 W FIR laser suitable for shipping and subsequent experimentation at site of the thermonuclear plasma devices.
2. Clarify mechanisms limiting performance of important FIR lasers.
3. Development parametric scaling laws and engineering guidelines for building high power cw lasers.
4. Develop new laser systems.

Milestones

1. Investigate new molecules for potential far infrared laser emission—October 1978.
2. Complete studies on CH_2F_2 laser system—November 1978.
3. Assembly and test of transportable FIR laser—January 1979.
4. Development of parametric scaling laws for optically pumped lasers—June 1979.

Graduate Students (% DOE support)

D. Birnbaum UCLA (100)

Graduates

None

Other Professional Staff

None

Professional Papers

A Review of Advances in Optically Pumped FIR Lasers, Infrared Physics (in press)

**A Versatile, High-Sensitivity X-Ray Imaging System for the Alcator Tokamak
(and for various magnetic mirror machines).**

Purpose

Approach

Seventeen surface barrier detectors view a cross-section of the Alcator plasma column through a small aperture; their outputs provide a one-dimensional image of the plasma emission profile. Filters are inserted in the optical path to modify the spectral response of the system as desired. Supplementary detectors are located at other positions around the torus to provide phase information useful in the analysis of MHD modes.

Solid state detectors and proportional counters are used to monitor radiation from the plasma in Constance I.

Progress

Data have been collected during Alcator plasma discharges characterized by a wide range of operating parameters. Measurements and analyses of the following types have been carried out with the Alcator data or are in progress:

1. Broadband spectral analysis of radiation in the EUV and soft X-ray energy ranges;
2. Study of emission (and its contribution to total power balance) as a function of position in the plasma;
3. Analyses of internal disruptions and determinations of electron and ion thermal conductivity coefficients (in collaboration with ORNL scientists);
4. Study of MHD activity during and prior to major disruptions;
5. Construction of movies which illustrate the time evolution of the plasma X-ray emission profile during various kinds of discharges, internal disruptions, and major disruptions.

6. Radiation spectral data from Constance I has been collected and analyzed.

Plans

1. Continue the work described above.
2. Determine (through theory and numerical experiments) optimized detector arrangements for collection of data to be used in the reconstruction of 2-dimensional maps of plasma structure.
3. Study the feasibility of using X-ray imaging techniques (in particular techniques for imaging cool plasmas) to study the plasmas in the various magnetic mirror machines at the Lawrence Livermore Laboratory.

Milestones

1. MIT mirror machine spectral studies—September 1978.
2. Alcator radiation studies—November 1978.
3. Alcator conductivity studies—November 1978.
4. Alcator MHD Studies—November 1978.
5. Two-dimensional imaging studies—November 1978.

Graduate Students (% DOE support)

Robert Granetz, M.I.T. (0%)

Graduates

None

Other Professional Staff

R. Chase	R. Krogstad
P. Gauthier	B. Pinsky
W. Hamilton	J. Ting
B. Holmes	

Major Recent Publications

None

Project

FIR Diagnostics

Luhmann

FY78 \$225K op

75K eq

Purpose

To develop new far-infrared diagnostic methods for use on large tokamak and mirror devices. Current emphasis is on an ion temperature measurement system for TFTR and MFTF.

Approach

Fusion plasma ion temperatures will be determined via submillimeter wave Thomson scattering. Present approaches under investigation include pulsed MW laser scattering from thermal plasmas and cw laser scattering from driven or spontaneously occurring ion cyclotron waves.

Progress

1. Development of first low noise FIR receiver suitable for ion temperature measurement.
2. Use of quasi-optical receiver to measure high harmonic synchrotron radiation from runaway electrons in Microtor tokamak.
3. Successful completion of first collective scattering measurements in the far-infrared. Radiation at both $875\text{ }\mu\text{m}$ and $447\text{ }\mu\text{m}$ was scattered from driven ion acoustic waves in an unmagnetized laboratory plasma.
4. Development of 1 W, long pulse ($\sim 50\text{-}150\text{ }\mu\text{s}$) FIR local oscillator for low noise heterodyne receiver in Thomson scattering diagnostic.
5. Development of high power pulsed $\text{C}^{13}\text{H}_3\text{F}$ 1.2 mm laser for initial pulsed ion temperature measurements.

Plans

1. Measure synchrotron radiation background from rebuilt Microtor device at frequencies from 200-1000 GHz.
2. Perform homodyne cw FIR laser scattering measurement to determine Microtor density fluctuation level at frequencies from $\approx 50\text{ kHz}$ to 500 MHz.

3. Determine tokamak ion temperature via cw scattering if spontaneously occurring electrostatic ion cyclotron waves are found.
4. Continue construction of portable pulsed FIR laser scattering system.
5. Complete interfacing of FIR receiver filter bank to Tektronix transient digitizer.

Milestones

1. cw FIR Laser Scattering on Microtor. Proposed installation date September 1.
2. Low frequency synchrotron measurements on Macrotor on schedule—September 1978.
3. Subharmonic Mixer Development—September 1978.
4. ECRH on Macrotor delayed. Attempt during August subject to machine availability—September 1978.

Project

An Experiment to Measure Low-Frequency Plasma Fluctuations by Large Aperture Homodyne Methods

Ralph H. Lovberg

FY77 \$113K op FY78 \$125K op

15K eq

Purpose

Measurement of density fluctuation spectra in plasmas of tokamak class. Spectral range of 1 to 0.1 cm spatial wavelength and 10 KHZ to 5 MHZ of primary interest.

Approach(es)

Low angle scattering of 10 micron infrared laser radiation is employed. Homodyne detection enhances signal-to-noise ratio when photoconductive detectors are used.

In order to obtain low frequency data, a long incident laser pulse (approximately 1 msec) is used, and a time series recorded for each machine pulse. On-line data processing equipment produces a spectrum of each event.

Progress

System temporal bandwidth has been increased to 200 MHZ.

Laser conversion to e-beam excitation has been completed. Maximum output power has been increased to 10 KW.

A program to identify and control residual laser noise in the 0.5 - 5 MHZ range has been undertaken. These fairly coherent lines are apparently due to beating between transverse optical modes in the unstable resonator. The theory of these modes is being studied by the Siegmann group at Stanford, and they are collaborating in these studies.

Plans

Continue with measurements of Microtor fluctuations (at UCLA).

The work on unstable resonator mode structure in CO₂ lasers will continue concurrently.

Milestones

Continue and complete Microtor fluctuation measurements—February 1979.

Extend the same measurements to Macrotor and obtain preliminary data—June 1979.

Graduate Students (% DOE Support)

Jack Shlachter (100%); Tom Angel (100%)

Project

Extreme Ultraviolet and Soft X-Ray Diagnostics of High Temperature CTR Plasmas.

H. W. Moos, L. Armstrong, Jr.

FY77 \$485K op FY78 \$44K op

61K eq

Measurements and Instrumentation

Purpose

To improve and use spectroscopic diagnostic techniques for the determination of impurity distributions and other properties of high temperature plasmas.

Approach

Design, construct and test new spectroscopic instrumentation for diagnostics in the EUV and SXR spectral region; perform EUV and SXR spectroscopic diagnostics on high temperature plasmas in cooperation with DOE laboratories.

Progress

Impurity densities and fluxes as well as the fraction of the input power lost through line radiation have been determined for the Alcator Tokamak; the spectroscopic studies show that hydrogen discharges in this tokamak have an effective Z close to one and in high density discharges the impurities have a poloidal asymmetry due to ∇B curvature drifts. A multispatial element spectrometer system has been completed and is being used to simultaneously view the plasma along twenty-two chords near the limiter. Studies of the neutral beam driven mirror device, 2XIIB, have determined the impurity concentrations, probable sources, and the fraction of the input power lost by line radiation. Spatially resolved ultraviolet measurements on Elmo Bumpy Torus have determined impurity concentrations both in the toroidal core and the blanket plasmas. A grazing incidence spectrophotometer for the transfer of absolute intensity calibrations from the NBS SURF II facility to DOE plasma facilities has been constructed. A multispectral element spectrophotometer is under development. Spatially resolved measurements of light impurities in Alcator was completed August 1977. An extreme ultraviolet study of impurity radiation from 2XIIB was begun July 1977.

Plans

1. Perform ultraviolet diagnostic studies at DOE plasma facilities; some of these experiments will utilize spatial resolution to determine impurity distributions and transport.
2. Design and construct new instruments for short wavelength diagnostics.

3. Prepare instrumentation capable of looking at many spatial and/or spectral elements in a single plasma shot.

Milestones

1. Complete evaluation of Spatial Imaging Detector System—September 1978.
2. Begin construction of Multispectral Element Spectrometer—January 1979.

Graduate Students

1. Project students (% DOE support, degree, years to complete):
S. Allen (100, Ph.D., 2); K. Chen (100, Ph.D., 1); P. Drake (100, Ph.D., 1); O. Strand (100, Ph.D., 2); J. Tyson (100, Ph.D., 2); R. Bell (100, Ph.D., 2), J. Castracane (100, Ph.D., 3).
2. Graduated during past three years (year, employed in fusion):
J. Ryley (M.S., 1976, no); J. Litke (Ph.D., 1976, no); J. Terry (Ph.D., 1978, yes).

Other Professional Staff

Wm. G. Fastie, Adjunct Research Professor of Physics, R. K. Richards, W. L. Hodge, and R. J. Dukart, Postdoctoral Fellows.

Major Recent Publications

R. K. Richards, Broadband Stable Detector for Ultraviolet (300-1700 Å) Plasma Spectroscopy, to be published in *Rev. Sci. Inst.*, 1978.

J. L. Terry, K. I. Chen, H. W. Moos and E. S. Marmor, EUV Impurity Study of the Alcator Tokamak, *Nuclear Fusion* 18, 485 (1978).

J. L. Terry, E. S. Marmor, K. I. Chen and H. W. Moos, Observation of a Poloidal Asymmetry in Impurity Ion Emission due to ΔB Drifts, *Phys. Rev. Lett.* 39, 1615 (1977).

E. S. Warden and H. W. Moos, The Penning Discharge as a Photoelectric Spectroscopy Source, *Appl. Opt.* 16, 1902 (1977).

Project

Laser Sources for Vacuum Ultraviolet Scattering in Fusion Plasmas

D. W. Koopman and T. J. McIlrath

FY77 \$ 0K op FY78 \$40K op
24K eq

Purpose

To develop a diagnostic technique to make spatially resolved neutral H, D, and T density measurements in magnetically confined fusion plasmas.

Approach

A tunable laser at 7296 Å is to be built, and the output wavelength converted to 1216 Å (Ly-alpha), by frequency doubling and tripling techniques. The 1216 Å beam will be used to achieve resonant scattering off neutral hydrogen atoms in a plasma.

Progress

1. Tunable 7296 Å laser radiation (1 J, 25 nsec, 1.5 Å bandwidth, near TEM-00) has been obtained, and converted to 3648 Å (>150 mJ, 20 n sec, near TEM-00) in a KDP crystal.
2. Conversion from 3648 Å to 1216 Å has been demonstrated, with ~200 W/Å obtained by tripling in pure krypton.
3. Measurements of optical mode patterns and calculations of theoretical factors affecting tripling efficiency indicate methods of achieving higher 1216 Å intensities.

Plans

1. Improve laser system so that the 3648 Å beam is appropriate for higher efficiency tripling.
2. Optimize tripling process by using krypton-argon or krypton-xenon mixtures, to achieve higher 1216 Å output.
3. Perform a simple scattering experiment to assess molecular hydrogen effects and to test scattering detection techniques.
4. Assess saturation effects and consequent upper limits to 1216 Å conversion efficiency and achievable power and energy.
5. Design scattering experiment for magnetically confined plasma.

Milestones

1. Obtain improved 1216 A output—December 1978.
2. Observe Lyman-alpha scattering in laboratory facility—April 1979.
3. Assess feasibility and cost of neutral density diagnostic for choices of magnetically confined plasma facilities—September 1979.

Graduate Students (% DOE support)

Y. M. Yui (0), S. Strobel (0)

Graduates

None

Other Professional Staff

Dr. Rita Mahon, Research Associate

Major Recent Publications

"Resonant Scattering of Lyman Alpha Radiation as a Neutral Density Diagnostic for Fusion Plasmas," D. W. Koopman, T. J. McIlrath, and V. P. Myerscough, J.Q.S.R.T. 19 555 (1978).

"Non-Linear Generation of Lyman-Alpha Radiation," R. Mahon, T. J. McIlrath, and D. W. Koopman, Appl. Phys. Letters (August 1978).

Project

Measurements and Instrumentation Development for Diagnostics of High Beta Plasma

A. DeSilva, R. Hess, G. Goldenbaum, and H. Griem

FY77	\$180K op	FY78	\$125K op
	14K eq		0 eq

Purpose

To diagnose formation and evolution of plasmas in reversed-field configuration.

Approach

A plasma is created using a theta pinch with a bias field antiparallel to the main field. Breaking and reconnection of magnetic field lines can produce a toroidally confined plasma, eliminating loss along open field lines. The evolution of the plasma is studied by various diagnostic techniques.

Progress

A crowbar switch has been installed on the main capacitor bank of the slow theta pinch (STP), permitting a longer-lived plasma. A parameter search has been started to find the most suitable plasma conditions for further studies. Reconnection and tearing have been measured in the fast theta pinch (FTP). Nonthermal density fluctuations were observed, including a feature with maximum wave vectors in the radial direction.

Plans

1. Increase bias magnetic field to allow easier production of reversed-field plasma.
2. Produce detailed study of plasma using Thomson scattering, optical spectroscopy, interferometry, and magnetic probes.
3. Complete field line mapping in FTP.

Milestones

1. STP bias bank upgrade—January 1979.
2. Investigate formation of reversed-field configuration in STP—August 1979.
3. Investigate stability of plasma field configuration—September 1980.

Graduate Students

J. Irby (100%), S. Gold (100%)

Graduates

S. Gold (1978) Ph.D.

Other Professional Staff

Dr. W. T. Chiang, Research Associate

Major Recent Publications

Experimental Study of the Axial Energy Distribution in a Fast Theta Pinch, T. T. Chiang and A. W. DeSilva, Phys. Fluids 21, 669 (1978).

Radial Ion Energy Measurements in a Fast Theta Pinch, T. T. Chiang and A. W. DeSilva, Phys. Fluids 21, 1053 (1978).

Observation and Interpretation of Magnetic Field Line Reconnection and Tearing in a Theta Pinch, J. H. Irby, J. F. Drake, and H. R. Griem, submitted for publication.

Comment

The emphasis in this task is changing from diagnostics development to investigation of plasma properties.

Project

Development of High Power Submillimeter Lasers for Diagnostics of Tokamak Plasmas.

D. R. Cohn, H. Fetterman, B. Lax

FY77(T)	\$171K op	FY78	\$233K op
	100K eq	(10 mos.)	30K eq

Purpose

Development of high power submillimeter (SMM) lasers and low noise SMM receivers and use them to establish the feasibility of Thomson scattering for ion temperature diagnostic of Tokamak plasmas.

Approaches

1. Optically pumped molecular gas SMM laser. A most suitable gas has been found to be D_2O , lasing at $385 \mu m$, when pumped with a CO_2 laser operating at the 9R(22) transition.
2. A specially developed Schottky barrier mixer diode, a quasioptical diode mount, and a quasioptical diplexer are assembled in a compact SMM receiver configuration.

Progress

1. Use of an etalon to provide single mode, tunable, high power CO_2 laser pump radiation. This development has afforded an increased SMM laser efficiency, improved spectral purity, and decreased superradiance.
2. 800 kW, 100 nsec pulses of high spectral purity at $385 \mu m$ were obtained from a D_2O oscillator with a conversion efficiency better than 0.3%.
3. Construction of a SMM receiver with a noise equivalent power of 2×10^{-19} W/Hz (double sideband).

Plans

1. Increase the pulse length of the CO_2 pump laser to 200 nsec, and boost the output energy of the D_2O oscillator to 150-200 mJ.
2. Develop instrumentation necessary to obtain the power spectrum of the scattered radiation.
3. Set up the Thomson scattering experiment in Alcator C.

Milestones

1. Complete laser work—February 1979.
2. Background radiation measurements on Alcator—April 1979
3. Set up laser system in Alcator C location—July 1979.
4. Initial measurements on Alcator C—September 1979.

Graduate Students (% DOE support)

None

Graduates (Year)

None

Other Professional Staff

W. Mulligan, H. C. Praddaude, P. Woskoboinikow, B. J. Clifton, P. Tannenwald

Major Recent Publications

1. High Power Optically Pumped Far Infrared Laser Systems, Z. Drozdowicz et al. IEEE J. Quan. Electronics QE13 (413), 1977.
2. Schottky-Barrier Diodes for Submillimeter Heterodyne Detection, B. J. Clifton. IEEE Trans. Microwave MTT25 (457), 1977.
3. Far-ir Heterodyne Radiometric Measurements with Quasioptical Schottky Diode Mixers, H. R. Fetterman et al., Applied Physics Letters 33 (151), 1978.
4. High Power Tunable 385 μm D₂O Vapor Laser Optically Pumped with a Single Mode Tunable CO₂ TEA² Laser, P. Woskoboinikow et al. (to be published in Journal of Applied Physics).

Project

Ion Beam Probe Plasma Diagnostic System

R. L. Hickok

5/77 - 5/79 \$430K op

Purpose

Develop diagnostic systems for making space and time resolved measurements in both open and closed confinement devices. Primary emphasis is the development and application of heavy ion beam probing.

Approach

A primary beam of heavy, singly charged ions is directed into the plasma and the doubly charged secondary ions created by electron impact are observed. The magnetic field separates the secondary ions according to their creation point providing 3-D spatial resolution. The intensity of secondary ions provides a measure of the electron density and temperature, their energy yields a direct measurement of the space potential, and their momentum can be related to the plasma current density. A variation of the technique is to inject a beam of heavy neutral particles and observe the singly charged secondaries created by electron impact. The approach followed is to develop diagnostic techniques on in-house facilities, RENTOR and ALEX, and then transfer the technology to major confinement experiments.

Progress

The significant achievements in the time period 1 August 1977 - 31 July 1978 have been:

1. Obtained equilibrium operation in the research tokamak facility, RENTOR. Pulses of ~ 5 msec duration with $I_p \sim 12$ kA are now routinely produced. Preliminary results indicate a minor plasma radius of 9 cm with a conductivity temperature of approximately 30 eV.
2. Obtained the Alice baseball coil from LLL and began installation of a mirror confined plasma experiment (ALEX). A heavy neutral beam has been designed for measuring space potential in the baseball geometry.

Plans

1. Perform space potential measurements in RENTOR with the heavy ion beam probe.
2. Perform a direct comparison between Thomson scattering and heavy ion beam probing on RENTOR.

3. Evaluate the capabilities of extracting the current density in tokamaks using a heavy ion beam probe.
4. Measure fluctuations in RENTOR using the heavy ion beam probe and standard diagnostic techniques.
5. Initiate the design of an RF heating experiment for RENTOR which emphasizes the capabilities of the heavy ion beam probe system for making spatially resolved measurements.
6. Measure space potential in ALEX using an arc plasma and a heavy neutral beam probe.
7. Initiate the design of a new experiment using the ALEX baseball coil which will allow investigation of the space potential distribution of mirror-confined plasmas. It is expected that gun injection into a high quality vacuum environment will be used.
8. Attempt to extend the frequency response of heavy ion beam probing specifically to look at microinstabilities in mirrors. The increased response would also be useful for RF heating experiments in tokamaks. Both high frequency chopping of the beam and direct energy modulation will be investigated.

Milestones

1. Obtain space potential measurements with the heavy ion beam probe on RENTOR—October 1978.
2. Comparison of beam probe and Thomson scattering measurements on RENTOR—January 1979.
3. Establish the experimental capabilities for measuring current density in tokamaks using a heavy ion beam probe—April 1979.
4. Obtain space potential measurements in ALEX—July 1979.

Graduate Students (% DOE support)

S. Biron (100), C. Fiore (100), J. Kolawole (50), K. Pourrezaei (50), T. Price (100), P. Schoch (100), L. Solensten (100).

Graduates

J. Glowienka (75), P. Woskoboinikow (76), J. Pipkins (78).

Other Professional Staff

W. C. Jennings, Associate Professor
 J. T. Woo, Associate Professor
 K. A. Connor, Assistant Professor
 A. Herscovitch, Research Associate

J. F. Pipkins, Research Associate
 R. E. Klinkowstein, Research Associate
 J. F. Lewis, Research Engineer

Major Recent Publications

"Heavy Ion Beam Probe Plasma Diagnostic System for the Deep Magnetic Well LITE Device," J. H. Stufflebeam, W. C. Jennings and R. L. Hickok, *IEEE Trans. Plasma Science PS-6*, 130 (1978).

"Direct Measurement of Plasma Space Potential on Elmo Bumpy Torus," P. L. Colestock, K. A. Connor, and R. L. Hickok, *Phys. Rev. Letters*, **40**, 1717 (June 1978).

Project

Development of a High Resolution, High Throughput Spectrometer
Suitable for Line Shape Diagnostics of X-Rays Emitted from Hot Plasmas

H. W. Schnopper, P. O. Taylor

FY77	\$120K op	FY78	\$180K op
	8.5K eq		8.5K eq

Purpose

Develop an instrument to provide high spectral resolution measurements of x-ray line profiles and ionic charge state distributions in a time dependent (pulsed) hot plasma. The instrument will be particularly suited for measurements in the photon energy range above about 0.5 keV, where contributions from important impurity ions can be investigated.

Approach

Design and build a curved crystal x-ray spectrometer with a high resolution linear detector. The range of Bragg angles subtended by the crystal is sufficient to reflect the resonance, forbidden and intercombination lines of the He-like series of heavy ion plasma impurities. The linear position sensitive detector is coupled directly to a minicomputer data analysis system which also controls the spectrometer functions.

Progress

During the current phase of the program:

1. A 16.8 cm x 9.6 cm PET crystal, bonded to a cylindrical surface is in-house.
2. A position sensitive proportional counter (PSPC) has been designed, fabricated, and partially tested.
3. Signal processing electronics for the above counter has been identified and is being fabricated.
4. The spectrometer vacuum system, mechanisms, and support structure were designed and fabricated.
5. The spectrometer and vacuum hardware were assembled.
6. A highly collimated x-ray source/test bench suitable for measuring the resolution of the PSPC was built and tested.
7. A contract was let for a portable, self-contained, Mo anode, microfocus x-ray tube and power supply.

8. MoL spectra showing presence of various charge states were obtained from Alcator A with a flat crystal spectrometer.

Plans

Phase 1: August 1, 1978 to July 31, 1979

1. Complete interface of the spectrometer with Alcator C.
2. Interface the spectrometer with a computer controlled data acquisition and analysis system.
3. Test the spectrometer on Alcator as an x-ray diagnostic tool.
4. Analyze and report diagnostic results and physics obtained.
5. Extend the spectroscopy to high resolution and/or to other regions of the spectrum as conditions permit.
6. Begin testing of mosaic crystals for increased sensitivity with high resolution.

Milestones

1. Complete position sensitive detector tests—September 1978.
2. Complete laboratory tests of spectrometer system—October 1978.
3. Begin computer installation—October 1978.
4. Begin setup at Alcator—November 1978.
5. Full operations at Alcator—January 1979.

Graduate Students

None

Graduates

None

Other Professional Staff

None

Major Recent Publications

None

ATOMIC, MOLECULAR AND NUCLEAR PHYSICS (AM) PROGRAM

This program provides atomic data for impurity ions and describes atomic processes involved in negative ion sources. The program includes spectroscopic data for highly ionized, heavy impurities (wavelengths, energy levels, transition probabilities) and cross sections for excitation, ionization, and recombination of such ions. An important part of the activity is the operation of an atomic data center to compile and distribute data as it becomes available.

Progress—Atomic, Molecular and Nuclear Physics

- The first experimental and theoretical data on charge exchange and ionization cross sections for hydrogen at neutral beam energies by multicharge ions, including iron, have been obtained. The data show that charge exchange with impurities is larger than expected while ionization, as estimated by present theory, is smaller. A universal curve for charge exchange cross sections and scaling of the cross sections with ion charge states has been determined. The results indicate that neutral beams will be able to penetrate large tokamaks if the expected low concentration of impurities is obtained (ORNL, LBL, SRI).
- Spectra for molybdenum ionized 31 times have been obtained from Nd: glass laser discharges at the Naval Research Laboratory. This is the highest ionization state for which detailed tokamak impurity data is now available. Spectral lines in 10-20 and 90-200 Å regions have been analyzed. A discharge temperature of nearly 1 keV is indicated from the distribution of ionization states. Wavelength determinations and a preliminary classification of the lines have been done. A comprehensive interpretation using relativistic theoretical calculations is in progress at NRL in collaboration with NBS and LASL.
- A new and greatly expanded compilation of cross sections for fusion research has been assembled with over 800 pages and 2500 data sheets (ORNL).
- A 50 KJ theta pinch facility has been placed in operation for cross section and rate measurements of impurity ions. Measurements of the ratio of dielectric satellite-to-resonance line intensity of 3 and 4 electron ions of oxygen have been made. Dielectronic recombination can now be obtained from a computer model of the line excitation. Measurements of ionization rate coefficients for Li-like oxygen and nitrogen ions have been completed and indicate that present theoretical values are too low (NBS).
- Measurement of the dielectronic recombination and ionization rates for 15 to 18 electron ions of iron have been made in a small theta pinch. Effective rate coefficients for recombination at electron densities $N_e \approx 3 \times 10^{16} \text{ cm}^{-3}$ have been found to be equal to or smaller than presently accepted theoretical values for low density plasma. The rate coefficient for ionization also appears to be smaller than theoretical values (Maryland).

Project

Atomic Physics (Experimental)

R. V. Pyle, K. H. Berkner

FY77	\$250K op	FY78	\$250K op
	25K eq		30K eq

Purpose

Investigate atomic physics phenomena related to neutral-beam injection systems: production of H^- and D^- ions in gases and vapors, and on surfaces; charge transfer and ionization of hydrogen atoms and molecules in collision with heavy highly stripped (trapped impurity) ions; neutralization of fast D^- in a plasma target; and neutralization, ionization, and dissociation of ions, atoms, and molecules found in neutral-beam lines.

Approach

Products of particle collisions in gases and plasmas, and at surfaces, are studied with the aid of three ion accelerators (200 eV - 25 keV, 500 eV - 30 keV, 2 keV - 300 keV) and a hydrogen-atom source in conjunction with gas and metal-vapor target cells (including a heat-pipe target and a high-temperature vapor cell), plasma targets, appropriate vacuum systems, and beam analysis and detection systems. The Super-HILAC heavy-ion accelerator (a source of highly stripped ions) is used in conjunction with a large 20 kG magnet and appropriate target and analysis chambers.

Progress

1. Construction and testing of an apparatus to study H^- and D^- formation by collision of thermal H^0 on clean and cesiated surfaces has been completed. The yield of H^- has been measured as a function of cesium fractional monolayer coverage. The work function of the surface has been measured as a function of cesium coverage.
2. Measurements of charge-transfer and impact-ionization cross-sections for fast highly stripped iron ions incident on molecular hydrogen have been completed for iron ions in charge states +3 to +25 and for energies of 110 keV/amu to 8.5 MeV/amu. A theoretical-experimental scaling rule for electron loss from a hydrogen atom in collision with a highly stripped ion has been obtained, which covers the energy range 50 keV/amu to 5000 keV/amu and the charge-state range from +1 to +50.
3. Charge-state-fraction measurements for 0.3 - 10 keV D^+ in a rubidium vapor target were completed. The D^- yield in a thick rubidium vapor target exceeds 25% at low energies.
4. Measurements of O^- stripping cross sections in He and Ar have been completed.

Plans

1. Measure H^- yield and energy distribution for 500 eV to 7 keV, and for thermal H^0 incident on a Mo substrate with a fractional-monolayer coverage of cesium simultaneous with measurement of the work function of the surface.
2. Complete measurements of cross sections σ_{-0} and σ_{0-} for 500 eV - 10 keV D^0 and D^- in cesium-vapor target.
3. Measure σ_{-0} and σ_{0-} , D^0 yield by interactions of 50-300 keV D^- in cesium and hydrogen plasmas.
4. Measure charge-transfer and target ionization cross sections for 3.4 MeV/amu Nb^{+q} in H_2 , for $q \sim 20-30$.

Milestones

1. Complete measurements of backscattered H^- yield for H ions on surfaces with thick layers of alkali metals—September 1978.
2. Complete measurements of cross sections σ_{-0} and σ_{0-} for D^0 and D^- in cesium vapor—October 1978.
3. Complete measurements of high-charge-state charge-transfer and ionization cross sections for Nb^{+q} in H_2 —April 1979.
4. Obtain first cross section for H^-/D^- charge exchange in hydrogen and cesium plasmas—May 1979.
5. Complete measurements of backscattered D^- and H^- yields for D and H ions on various substrates with partial cesium coverage—June 1979.
6. Complete measurements of H^- production on Cs-coated Mo surface bombarded by thermal H as a function of surface work function—June 1979.

Graduate Students (% DOE support)

P. J. Schneider (100%), S. E. Savas (100%), K. R. Stalder (100%)

Graduates

None

Other Professional Staff

W. G. Graham, A. S. Schlachter, and J. W. Stearns

Major Recent Publications

"Charge-State Dependence of Electron Loss From H by Collisions with Heavy Highly Stripped Ions," R. E. Olson, K. H. Berkner, W. G. Graham, R. V. Pyle, A. S. Schlachter, and J. W. Stearns, Phys. Rev. Letters **41**, 163 (1978).

"Electron-Capture and Impact-Ionization Cross Sections for Partially Stripped Iron Ions Colliding with Atomic and Molecular Hydrogen," K. H. Berkner, W. C. Graham, R. V. Pyle, A. S. Schlachter, J. W. Stearns, and R. E. Olson, J. Phys. B. **11**, 875 (1978).

Project

Ion Source Research

W. B. Kunkel, C. F. Burrell, C. F. Chan, W. S. Cooper, K. W. Ehlers

FY77	\$100K op	FY78	\$100K op
	11K eq		0 eq

Purpose

To investigate, develop and optimize neutral-beam injector ion sources for present and planned MFE experiments.

Approach

Diagnostic techniques, such as Langmuir probes, spectroscopy, and mass spectrometry, as well as computer modeling, are being used to study both the conditions inside the LBL ion sources and characteristics of the resulting ion beams. Modifications are made in search of more efficient operation, extension to dc conditions, or negative ion production.

Progress

1. We have essentially completed rebuilding our physics test facility (Test Stand I) to upgrade its capabilities and comply with current safety standards.
2. We developed a computer program to calculate hydrogen ionization rate coefficients for arbitrary optical thickness.
3. We developed an automated Langmuir probe instrumentation system, using a digital transient recorder and a computer for on-line data analysis. In addition to normal Langmuir probe characteristic analysis, this system can measure directly the electron energy distribution function.
4. Typical measurements of the electron energy distribution in one of our sources made with this equipment indicates that from 90 to 97 percent of the electrons are thermal, and that there is a nonthermal high energy tail containing even some electrons with energies 10 to 15 eV greater than the maximum cathode fall (Langmuir's Paradox, again!).
5. We have completed a parameter study of the standard LBL type source, and find that the source operates according steady-state, low pressure discharge theory.
6. We have developed an analytic model for determining the relative atomic and molecular ion output from an LBL-type ion source, and are just finishing calculation of all the rate coefficients (from measured cross-sections) needed to apply it.
7. We have begun extending the 1-D computer model of the source to include molecular ions.

Plans

1. We have been unable to find and hire an additional good physicist to participate in this research, but we hope to during FY79. This is essential, or our progress is hampered by diversion of physics effort to the Neutral Beam Development Program.
2. Major emphasis will be on understanding the mechanisms for H^+ and D^+ production in sources, and on maximizing these ionic fractions in the beam.

Milestones

1. Complete the new 1-D computer model for prediction the ionic composition of beams and compare with experiment.
2. Construct and begin testing a new improved ion source (carried over from FY78).

Graduate Students

1. Project students (% DOE support, degree, years to complete):
B. D. Billard* (100, Ph.D., 0.5); K. F. Schoenberg (100, Ph.D., 1)
2. Graduated during past three years: none (Project started FY76).

*Carry-over from spectroscopic diagnostics which has been phased out.

Project

Atomic and Molecular Physics

C. F. Barnett, R. L. Becker, H. J. Kim, F. W. Meyer, R. A. Phaneuf

FY77	\$390K op	FY78	\$380K op
	20K eq		30K eq

Purpose

To measure atomic data needed in understanding the heating, cooling, loss, and diagnostics of high temperature plasmas.

Approach

Monoenergetic particle beams in the energy range 20 eV to 10 MeV are passed through static gas cells or crossed with an energetic neutral or charged beam to determine absolute cross sections. Facilities available include six accelerators: (1) 0.02-2 keV; (2) 1-50 keV; (3) 20-600 keV; (4) 1-15 MeV tandem; (5) 5-150 keV multicharged ion; and (6) 10-100 keV H^0 accelerator. In addition to the usual electronic and vacuum equipment, two beam-scattering chambers are available to perform crossed-beams experiments in 10^{-10} Torr vacuums.

Progress

1. Preliminary measurements were obtained for the total electron loss and ionization cross section of H^0 by N^{4+} , N^{3+} , N^{2+} , and O^{4+} in the energy range 40-60 keV.
2. Measurements of the electron capture cross sections of Si^{q+} , Mo^{q+} , and Fe^{q+} in the energy range 60-160 keV/amu revealed ion shell effects when the cross section was plotted as a function of ion charge. For Ta^{q+} , W^{q+} , and Au^{q+} , oscillations in the cross sections as a function of the ion charge were attributed to interference between long-range and short-range Coulomb potentials during the collision.
3. Remeasurement of the D^- from D^+ or D^- passing through Cs vapor resulted in an equilibrium fractional yield of 0.21 at 375 eV/amu.
4. A CAMAC-based data acquisition system has been placed into operation on the crossed-beams facilities.
5. A 10-J CO_2 laser beam focused to a power density of 10^9 - 10^{10} W/cm² on carbon has produced usable beams of C^{5+} and C^{6+} .
6. A full quantum calculation of the electron capture cross section of O^{6+} on H has been completed. Excellent agreement was obtained with experimental data and with classical Monte Carlo computations.

Plans

1. Complete ionization cross section measurements of H^0 with C^{n+} , O^{n+} , and Fe^{n+} in the energy range 20-100 keV.
2. Measure electron capture cross sections for C^{5+} , C^{6+} , O^{7+} , and O^{8+} in H and H_2 in energy range 1-5 keV.
3. Obtain preliminary electron capture cross sections of H^+ with C^{q+} and O^{q+} .
4. Determine electron capture cross sections σ_{10} of H^0 in Cs vapor and electron stripping cross sections σ_{-10} of H^- in Cs vapor in the energy range 100 eV-2 keV.
5. Measure electron capture cross sections of W^{q+} , Au^{q+} , and Mo^{q+} in H in the energy range 0.1-0.15 keV/amu.
6. Extend the full quantum calculations of electron capture cross sections to ions of Fe and Ta.

Milestones

1. Complete measurements of ionization cross sections of H^0 with multicharged ions at TFTR energies—July 1979.
2. Measure electron capture cross sections of W^{q+} , Au^{q+} , and Mo^{q+} with H and H_2 in energy range 0.1-0.5 keV/amu—January 1979.
3. Use laser ion source to measure low-energy electron capture cross sections of C^{5+} , C^{6+} , O^{7+} , and O^{8+} in H and H_2 —July 1979.
4. Determine cross sections for reactions D^0 and D^- in Cs vapor for energies less than 2 keV—January 1979.
5. Initiate measurements of cross sections of H^+ with multicharged ions—July 1979.

Graduate Students

None

Graduates

None

Other Professional Staff

None

Major Recent Publications

1. H. J. Kim, R. A. Phaneuf, F. W. Meyer, and P. H. Stelson, "Single Electron Capture by Multicharged ^{28}Si Ions in Atomic and Molecular Hydrogen," *Phys. Rev. A* **17**, 854 (1978).
2. R. A. Phaneuf, F. W. Meyer, and R. H. McKnight, "Single Electron Capture by Multiply Charged Ions of Carbon, Nitrogen and Oxygen in Atomic and Molecular Hydrogen," *Phys. Rev. A* **17**, 534 (1978).
3. H. J. Kim, P. Hvelplund, F. W. Meyer, R. A. Phaneuf, P. H. Stelson, and C. Bottcher, "Observation of Oscillations in the Charge Dependence of Total Electron Capture Cross Sections," *Phys. Rev. Lett.* **40**, 1635 (1978).
4. C. Cisneros, I. Alvarez, R. Garcia, C. F. Barnett, J. A. Ray, and A. Russek, "Electron Capture to D_3^- and D_3^0 Repulsive States by D_3^+ in Cs," accepted for publication in *Phys. Rev. A*.
5. F. W. Meyer, R. A. Phaneuf, H. J. Kim, P. Hvelplund, and P. H. Stelson, "Single Electron Capture Cross Sections for Multiply Charged O, Fe, Mo, Ta, W, and Au Ions Incident on H and H_2 at Intermediate Energies," submitted to *Phys. Rev. A*.
6. D. H. Crandall, R. A. Phaneuf, and F. W. Meyer, "Electron Capture by Slow Multicharged Ions in Atomic and Molecular Hydrogen," submitted to *Phys. Rev. A*.
7. R. E. Olson, A. Salop, R. A. Phaneuf, and F. W. Meyer, "Electron Loss by Atomic and Molecular Hydrogen in Collisions with $^3\text{He}^{++}$ and $^4\text{He}^+$," *Phys. Rev. A* **16**, 1867 (1978).

Project

Controlled Fusion Atomic Data Center
C. F. Barnett, S. W. Hawthorne, M. I. Wilker
FY77 \$160K op FY78 \$170K op
 0 eq 0 eq

Purpose

To evaluate published data and to publish in the form of a handbook and newsletter those atomic data of interest to MFE.

Approach

Search refereed and report literature, perform evaluations, and compile data consistent with the needs of magnetic fusion energy research.

Progress

1. Continued publication of bimonthly newsletter, "Atomic Data for Fusion," in cooperation with NBS.
2. Searched literature on current basis.
3. Initiated new computer input-output program for storing and retrieving bibliographical data.
4. Started compilation of multicharged impurity-ion cross sections.
5. Completed computer storage and retrieval system for numerical data, including cross sections and reaction rates.

Plans

1. Complete compilation of cross sections for impurity ions found in magnetically confined plasmas.
2. Update *Atomic Data for Controlled Fusion Research*, Vols. I and II.
3. Attempt evaluation of theoretical cross sections and include theoretical predictions in data compilations.
4. Publish four bibliographies on heavy particle collisions for 1950-75.
5. Continue publication of "Atomic Data for Fusion."

Milestones

1. Update compilation *Atomic Data for Controlled Fusion Research*—March 1979.
2. Publish four bibliographies—January 1979.
3. Complete conversion of cross sections to reaction rates and publish as a compilation—July 1979.

Graduate Students

None

Graduates

None

Other Professional Staff

D. H. Crandall	F. W. Meyer
H. B. Gilbody	T. A. Morgan
H. J. Kim	R. A. Phaneuf
E. W. McDaniel	J. A. Ray
R. H. McKnight	E. W. Thomas
G. S. McNeilly	

Major Recent Publications

1. C. F. Barnett and W. L. Wiese, "Atomic Data for Fusion," Vols. 3 and 4, 1977-78.
2. C. F. Barnett, "Role of Impurities in Magnetically Confined High-Temperature Plasmas," p. 375 in *Atomic Physics V*, ed. by R. Marrus, M. Prior, and H. Shugart, Plenum Press, New York, 1977.
3. C. F. Barnett, "Controlled Fusion Atomic Data Center," *Trans. Am. Nucl. Soc.* **26**, 567 (1977).

Project

The determination of atomic, molecular and nuclear data pertinent to the Magnetic Fusion Energy Program

J. E. Leiss

FY77 \$560K op FY78 \$640K op
55K eq

Purpose

To develop the atomic, molecular and nuclear physics data base required for: Plasma diagnostics and plasma modelling, analysis of heavy ion impurity physics, study of plasma heating and cooling mechanisms, and neutral beam injection systems.

Approach

Electron-ion collision cross sections, radiative transition probabilities, dielectronic recombination and collisional transition rates and the wavelengths of prominent spectral lines are experimentally and theoretically determined. The wavelength and energy level data will also be compiled and tabulated. Far UV and soft x-ray radiometric standards are developed to provide radiometric calibrations for laboratory instruments throughout the fusion energy program. The d-t fusion reaction cross section will be determined through a measurement of its inverse reaction $n + {}^4\text{He} \rightarrow \text{d} + \text{t}$, using high resolution neutron time-of-flight techniques. Other neutron transport and reaction cross sections in the energy region of interest will be also experimentally determined.

Progress

1. Work on Y, Zr, Nb and Mo concentrated on measurements of spectra of highly stripped copper and zinc-like ions with laser produced plasmas. 4s-4p resonance lines and other prominent transitions were observed past Mo extending to Sn XXI and XXII. Collaborative work with NRL and LASL on interpretation of Mo spectra obtained with an Nd-glass laser lead to identification of spectra of the Al, Ng and Na-like atoms: Mo XXX, XXXI, and XXXII. The NBS Nd-glass laser now produces ions up to Fe XX, the new 2.2 meter grazing incidence spectrograph extends the range of observation down to 15 Å and the laser produced plasmas are also observed in the 8 to 17 Å range with a high resolution x-ray crystal spectrometer on loan.
2. The critical compilation of energy levels for all spectra of manganese was published and similar compilations for vanadium and titanium completed. The literature on all atomic spectra is monitored and references supplied for each issue of the newsletter "Atomic Data for Fusion".

3. On the θ -pinch facility ionization rate coefficients were measured for Li-like oxygen and nitrogen ions and a paper submitted to Physical Review. A systematic trend was found when all measurements of Li-like rate coefficients are combined, and has been analyzed. To introduce heavy elements into the discharge a pulsed washer-gun source has been developed and is studied on titanium. Measurements of dielectronic satellite-to-resonance line intensity ratios for the Li-Be system of oxygen have been made and strong satellites have been found and analyzed.
4. Calculations of the total rate of dielectronic recombination of Mo XXXIII to form Mo XXXII have been carried out, using previously computed atomic data generated specifically for these ions. The computed rate agrees with the Burgess-Merts formula quite closely, but some contributing stabilizing transitions are very poorly described by the Burgess-Merts approach.
5. Measurements for the excitation of the $2s-2p$ transition in N^{4+} and for the excitation of the $2\ ^3P$ level of Li^+ have been completed. The work on N^{4+} has been reported at a national meeting and has been written up for publication. Preliminary measurements for the excitation of the $4\ ^2P$ level of Zn II have been completed.
6. Radiometric transfer standard photodiodes calibrated down to 5 nm have been supplied to users. A study of various photocathode materials used by plasma diagnosticians has been started. Monochromators have been calibrated at SURF for the Johns Hopkins University diagnostic group. In February, the second workshop on the use of XUV and x-ray radiometry in plasma diagnostics was held.
7. X-ray detector calibrations were provided for MFE laboratories. Work to further improve characterization of the x-ray spectra of the NBS sources was undertaken using high resolution spectrometer systems.
8. Measurements and analyses of the neutron standards $^{235}U(n,f)$ and $^{237}Np(n,f)$ were completed for the 2-20 MeV neutron energy interval. The $N + ^4He$ total cross section near the 22.15 MeV neutron energy resonance was measured with a resolution approximately four times better than previous measurements.

Plans

1. Utilize high power Nd-glass laser at Los Alamos to observe spectra of very highly ionized atoms (Mo^{+31} , W^{+45}). With NBS high power laser, lines of Li-like Ti XX will be studied. Attempts will be made to analyze highly ionized tungsten ions by working on the Ag isoelectronic sequence.
2. We plan to complete critical compilations for all calcium and potassium ionic spectra. A new bibliography will be published.
3. Measurements of ionization rates for heavy ions of Ti and possibly Xe will be undertaken. Improvement of the diagnostic instrumentation by utilizing holographic interferometry is planned. Dielectronic satellite-to-resonance line intensity ratios of oxygen ions will be measured.

4. Total rates of dielectronic recombination of Mo XXXII to form Mo XXXI will be undertaken. The fundamental atomic physics of the processes will be further explored and plasma density effects will be studied.
5. Work on excitation cross sections will be started on beryllium sequences and sodium sequence ions. The Second Conference on Atomic Processes in High Temperature Plasmas will be hosted at JILA.
6. Transfer standard detectors will be supplied as required. More stable photo-cathode materials will be explored, and a small grazing incidence transfer standard monochromator will be built, tested and calibrated.
7. X-ray spectra of steady state calibration sources in the energy range from 270 eV to 10 keV will be measured and calibration services will be supplied for laboratories involved in low energy x-ray measurement.
8. Key total cross sections up to 40 to 50 MeV will be measured for neutron model testing and adjustment and preparation for neutron transfer and reaction cross sections. A high energy standard neutron detector will be calibrated to 20 MeV.

Major Milestones

1. 0 dielectronic satellite measurements—December 1978.
2. Host 2nd Conference on APHTP—January 1979.
3. Calibrate Oak Ridge and Princeton solid state detectors by x-ray line sources—January 1979.
4. Measurements on resonance line of B II—April 1979.
5. Analyze spectra of Mg- and Na-like Mo XXXI and Mo XXXII—June 1979.
6. Xe and Ti ionization rate measurements—July 1979.
7. Complete energy-levels compilation for Ca I through Ca XX and through K XIX—September 1979.
8. Construction, testing and calibration of small grazing incidence transfer monochromator—September 1979.
9. Complete first 10-40 MeV total cross sections—September 1979.
10. Total rate of Mo XXXII to form Mo XXXI—December 1979.
11. Complete neutron detector calibration to 20 MeV—December 1979.

Graduate Students (% DOE support)

W. Rodgers (60%)

Graduates

None

Other Professional Staff

Dr. J. Reader	Dr. E. Saloman
Dr. R. Zalubas	Dr. G. Dunn
Dr. W. C. Martin	Dr. L. J. Roszman
Dr. J. R. Roberts	Dr. C. D. Bowman
Dr. W. R. Rowan	Dr. A. D. Carlson
Dr. J. Sugar	Dr. R. P. Madden
Dr. J. Sparrow	Dr. W. L. Wiese

Major Recent Publications

1. 4s-4p Resonance Transitions in Highly Charged Cu- and Zn-like Atoms, J. Reader and N. Acquista, Phys. Rev. Lett. **39**, 184 (1977).
2. Spectra of Mo XXX, XXXI, and XXXII from a Laser-Produced Plasma, P. G. Burkhalter (NRL), J. Reader (NBS), and R. D. Cowan (LASL), J. Opt. Soc. Am. **67**, 1521 (1977).
3. Energy Levels of Manganese, Mn I through Mn XXV, C. Corliss and J. Sugar, J. Phys. Chem. Ref. Data **6**, 1253-1329 (1977).
4. Energy Levels of Vanadium, V I through V XXIII, J. Sugar and C. Corliss, J. Phys. Chem. Ref. Data, in press, June 1978.
5. Electron Impact Ionization Rate Coefficients for Lithium-like Nitrogen and Oxygen, W. L. Rowan and J. R. Roberts, submitted to Phys. Rev.
6. Dielectronic Recombination of Mo XXXIII, L. J. Roszman, submitted to Phys. Rev. Letters.
7. Absolute Cross Sections for 2S-2P Excitation of C^{3+} by Electron Impact, P. O. Taylor, D. Gregory, G. H. Dunn, R. A. Phaneuf, and D. H. Crandall, Phys. Rev. Letters **39**, 1256 (1977).
8. Absolute Cross Section for Electron Impact Excitation of Li^+ to the 2^3P Level, W. T. Rogers, J. Ø. Olsen, and G. H. Dunn, Phys. Rev. A (accepted for publication).
9. Typical Photoefficiency Between 20 and 250 eV of Windowless XUV Photodiodes with Tungsten and Anodized Aluminum Oxide Photocathodes, E. B. Saloman, Applied Optics **17**, 1489 (1978).
10. Measurements of the ^{235}U Fission Cross Section in the MeV Energy Region, A. D. Carlson and B. H. Patrick, International Conference on Neutron Physics and Nuclear Data for Reactors and Other Applied Purposes, Harwell, September 25, 1978.

Project

Spectroscopic Data Center (XUV Compilation)
Raymond L. Kelly
FY77 New FY78 \$20K op

Purpose

To prepare a new compilation of spectral lines with wavelengths below 2000 Angstroms (for the first 36 elements).

Approach

Information on wavelengths and atomic energy levels is extracted from the published literature. Redundancy is eliminated, and published classification validated, by a line-by-line comparison between observed wavelengths and those predicted from the levels.

Progress

1. The literature search has been maintained on a continuing basis.
2. A complete revision of previous reports, incorporating the latest data, has been completed for the first 12 elements.
3. All new data on wavelengths and energy levels to March 1978 have been punched onto cards for incorporation into the files.

Plans

1. Continue the literature search and data acquisition.
2. Update the existing card files by comparing new observations of spectral lines with best values of atomic energy levels.
3. Write magnetic tapes of interim compilation, from time to time, for distribution to interested researchers.

Milestones

1. Update the compilations of spectral lines and atomic energy levels for the first 18 elements—January 1979.

Graduate Students

None

Graduates

None

Other Professional Staff

None

Major Recent Publications

None

Project

Charge Capture Experiments for Plasma Ions and Neutral Atoms

R. C. Elton, R. H. Dixon

FY77 \$60K op FY78 \$70K op

Purpose

The goal of this project is to demonstrate in a controlled experiment the significance of resonance charge transfer as an ionization/recombination process in a plasma medium. In particular, electron transfers from neutral atoms to specific excited levels and sublevels of various impurity ions are investigated.

Approach

Ionized atoms are formed from a laser-vaporized disc. A buffer gas surrounding the target interacts with the initial expanding plasma and creates the proper ion-neutral conditions for resonance charge transfer. Spectroscopic observations of the plasma determine spectral line enhancement which defines the specific excited ion level(s) participating in electron capture. The dynamic formation and transport of neutral atoms and ions are mapped with time-resolved spectroscopic techniques.

Progress

With a carbon disc and using grazing incidence spectroscopy in the 30-300 Å region, anomalous emission originating on the $n=4,5$ levels in C^{4+} and C^{5+} ions have been associated with population by resonance charge transfer from carbon atoms. Agreement for 1st and 2nd series denies anomalies reported in ORNL measurements. Numerical analysis distinguishes charge transfer from free-electron capture. Neutral hydrogen is injected for (C^{n+}, H) reactions.

Plans

1. Trace the source of neutrals from early times in the buffer gas.
2. Map the particle dynamics (r,z,t) from numerical spectroscopic analyses.
3. Analyze the transition boundary for e-capture relaxation rate coefficients.
4. Continue the experiments with injected hydrogen atoms and carbon "impurity" ions.

Milestones

1. Complete (r,z,t) mapping of particle dynamics in interaction zone—November 1978.
2. Find origin of early neutrals and process(es) involved—January 1979.
3. First analysis of transition boundary for capture rate coefficients—January 1979.
4. Measure densities, temperature with hydrogen injection—April 1979.
5. Remeasure x-ray emission with hydrogen and with time-resolution—July 1979.
6. Deduce capture rates with carbon ions and hydrogen—September 1979.
7. Extend experiments to heavier elements—October 1979.

Graduate Students (% DOE support)

None

Graduates (Year)

None

Other Professional Staff

John F. Seely, NRC Postdoc

Major Recent Publication

"Intensity Inversion in the Balmer Spectrum of C^{5+} ", by R. H. Dixon, J. F. Seely and R. C. Elton, Physical Review Letters **40**, 122 (1978).

Project

X-UV Spectroscopy in Support of the CTR Program

P. G. Burkhalter and D. J. Nagel

FY77 \$70K op FY78 \$70K op

Purpose

To provide wavelength data in the x-ray and ultraviolet region (2-300 Å) from metallic elements (Fe, Mo, and W) and inert gases (Ar, Kr, and Xe) excited in high temperature plasmas (1-3 keV); these data will be used for analyses of Tokamak impurity and injection gas.

Approach

Radiation from high density plasmas in exploded wires and focused-laser sources, and gas puff or vacuum discharge devices, is measured with x-ray diffracting crystals and grating spectrographs. Ab initio calculations and isoelectronic extrapolation are used to classify the resulting spectra.

Progress

1. Accurate wavelengths of Mo- and Na-like transitions in Mo XXXI and Mo XXXII were determined in the 10-200 Å region from data obtained with the Nd:glass laser system at the Naval Research Laboratory. The laser generated a 1 keV Mo plasma.
2. Spectra from Mo XXXI-Mo XXXIV in the 3-6 Å region were obtained from single and multiple wire experiments performed at the Naval Research Laboratory and at Physics International Company. The exploded-Mo-wire plasmas had temperatures of 2.5-3 keV. Detailed line classifications were made in F-like Mo XXXIV.
3. A gas-puff discharge device capable of producing high density Z-pinched plasmas with temperatures of 1-2 keV became operational at the University of California (Irvine). X-ray spectra were collected in collaboration with Dr. Joseph Shiloh from highly ionized inert gases (Ar and Kr) in the 3-8 Å region. Wavelength measurements and line classifications were made for Ne- and F-like Kr XXVII and Kr XXVIII. A report of these measurements is in progress.

Plans

1. Collect and interpret x-ray and UV spectra taken with laser, exploded-wire, and gas puff or vacuum spark discharge sources.
2. Design and evaluate spectrographs for use on Tokamaks and hot, dense sources.

Milestones

1. Analyse spectral data collected from elements Fe, Nb, and Mo emitted by plasmas generated with focused ruby and CO₂ lasers.
2. Report on the satellite line structure in Fe XVI and Ti XII from data generated by the glass laser and the vacuum spark device.
3. Collect and interpret x-ray and UV data from tungsten generated in a hot, dense plasma source.
4. Collect and interpret UV data (10-200 Å) from gas puff Z pinch discharges in Ne, Ar, Kr, Xe, and possibly WF₆.

Graduate Students (% DOE support)

None

Graduates (Year)

Not applicable

Other Professional Staff

J. W. Criss (20%)

Major Recent Publications

1. "Spectra of Mo XXX, XXXI, XXXII from Laser-Produced Plasma," P. G. Burkhalter, Joseph Reader, and Robert D. Cowan, J. Opt. Soc. Am. **67**, 1521 (1977).
2. "Spectra of Mo XXXI-XXXIV from Exploded-Mo-Wire Plasmas," P. G. Burkhalter, R. Schneider, C. M. Dozier, and Robert D. Cowan, Phys. Rev. A **17** (Aug. 1978).
3. "X-Ray Line Emission and Plasma Conditions in Exploded Fe Wires," P. G. Burkhalter, C. M. Dozier, C. Stallings, and Robert D. Cowan, J. Appl. Phys. **49**, 1092 (1978).

Project

Excitation and Ionization of Ions by Electron Impact

R. K. Feeney

FY77	\$40K op	FY78	\$40K op
	0 eq		0 eq

Purpose

1. Measurements of the absolute cross sections for electron impact triple and quadruple ionization of Rb^+ , Cs^+ , and Tl^+ ions;
2. Measurements of the absolute cross sections for the electron impact single and double ionization of Cu^+ , Mo^+ , and Au^+ ions;
3. Measurements of electron capture and stripping cross sections of Cu, Ni, Au, and Mo singly charged ions and neutrals, respectively; and
4. Continuation of ion source development leading to a laboratory-size source of multiply-charged metallic ions.

Approach

Ionization measurements are made using crossed ion and electron beams which intersect in a well-defined collision volume. Charge exchange measurements are made by passing a beam of the projectile particle through a gas cell and analyzing the emerging beam.

Progress

1. Final measurements of the electron impact triple and quadruple ionization cross sections of Rb^+ ions are under way.
2. Particle optics of the ionization experiment have been improved to reduce experimental scatter.
3. Testing of the metal-ion source has been completed. It will be connected to the ionization experiment upon completion of the alkali-ion measurements.
4. The charge exchange apparatus is in the design phase.

Plans

1. Completion of the measurements of multiple ionization of alkali ions.
2. Measurements of the electron impact ionization of metallic ions.
3. Construction of the charge exchange apparatus.

Milestones

1. Completion of the Rb^+ multiple ionization measurements—September 1978.
2. First Au^+ ionization measurements—December 1978.
3. Completion of the charge exchange apparatus—May 1979.

Graduate Students (% DOE support)

D. W. Hughes (50%), D. C. Priester (33%)

Graduates (year)

D. Baggett (1977)

Other Professional Staff

None

Major Recent Publications

None

Project

Atomic Physics in High-Temperature Plasmas

R. Datla and H. R. Griem

FY77 \$ 0 op FY78 \$60K op

Purpose

Measure excitation, ionization, and recombination rate coefficients of highly ionized iron ions.

Approach

Quantitative spectroscopy of highly ionized iron ions in a θ -pinch plasma.

Progress

Measured the dielectronic recombination rates for Fe IX - Fe XI.

Plans

1. Measure excitation rates for Fe XI and Fe XII.
2. Extend the measurements of ionization and recombination to higher ions, e.g., Fe XII, Fe XIII, etc., using longer-lived plasmas in the crowbarred mode.
3. Interact with TEXT-Tokamak group, for possible use of TEXT to extend these measurements to even higher ionization stages of iron.
4. Replace zero-dimensional rate equation computer model by one-dimensional model.

Milestones

1. Measure excitation rates of Fe XI and Fe XII—March 1979.
2. Measure ionization and recombination coefficients for higher ionization stages of iron—December 1979.
3. Measure excitation rate coefficients for higher ionization stages of iron—November 1980.

Graduate Students

Robert L. Brooks (100%)

Graduates

R. L. Brooks, Ph.D. (1978)

Other Professional Staff

Dr. W. T. Chiang, Research Associate

Major Recent Publications

Measurement of Dielectronic Recombination Rates for the Iron Ions Fe IX - Fe XI, Phys. Rev. Lett. 41, 107 (1978).

Measurement of Effective Ionization and Recombination Rate Coefficients for Intermediate Ions in a Laser-Generated Theta-Pinch Heated Plasma, R. L. Brooks, Jr., Ph.D. Thesis, University of Maryland Technical Report #78-100 (1978).

Project

Cross Sections and Equilibrium Fractions of D^+ and D_2^+ in Metal Vapors

Thomas J. Morgan

FY77 AF

FY78 \$25K op

Purpose

Measure cross sections for formation of negative deuterium ions (D^-) by charge exchange of positive deuterium ions (D^+) and dissociation of positive molecular deuterium ions (D_2^+). Also measure equilibrium negative ion fractions.

Approach

Measure the yields of D^+ , D^- , and D^0 as a function of target thickness. Obtain cross sections from the slope of the curve of yield vs. thickness. As the target thickness is increased, the yields will eventually become constant. These values are the equilibrium yields.

Progress

1. Completed cross section measurements for single and double electron capture in both Mg and Ba targets over the energy range from 2.2 to 180 keV.
2. Completed negative ion equilibrium fraction measurements for $D^+ + Ba$ collisions.
3. Complete D^- equilibrium measurements for $D^+ + Ca$ and $D^+ + Mg$ (April 1978).
4. Complete equilibrium measurements for $D_2^+ + Mg$ collisions (July 1978).

Plans

1. Complete study of D^- equilibrium fractions using D^+ beams.

Milestones

1. Complete D^- equilibrium measurements for $D^+ + Sr$ —October 1978.

Graduate Students (% DOE support)

Marguerite Mayo (0)

Graduates

None

Other Professional Staff

Jack Stone

Major Recent Publications

1. Double Electron Capture in $H^+ + Mg$ Collisions, T. J. Morgan and F. Eriksen, *Phys. Lett.* 66A (1978) 198.

Electron-ion Collision Studies Relevant to the CTR Program
J. Wm. McGowan, H. R. Froelich, T. M. Luke and P. Mul
FY77 \$65,000 op FY78-79 \$196,000 op
 65,000 eq

To measure cross-sections for electron-ion recombination, excitation and ionization needed by the CTR program.

To continue to utilize a merged electron-ion beam apparatus MEIBE-I for studies of relevant dissociative recombination and ion excitation studies while completing MEIBE II which will be used primarily for dielectronic recombination studies. To continue to measure and calculate differential ionization cross-sections for ion foil and ion atom collisions.

1. Measured and/or remeasured with MEIBE I

- a. dissociative recombination cross-sections between 0.007 and ~ 2 eV for the following species:

Papers are in preparation or submitted for publication.

- b. the effects of excitation of some species on recombination.
2. Nearly completed the final design of MEIBE II. Construction is now beginning.
3. The test chamber for the He^+ (2s, 2p) excitation experiment is completed.
4. Charge transfer into the continuum measurements and theory for both foils and atoms are now completed and in preparation for publication or published.
5. An active cooperative program has been developed with the Université-de-Louvain-la-Neuve where superimposed beam experiments relevant to our program are underway. Prof. W. Claeys of this laboratory, Prof. F. Reed, University of Manchester and Prof. W. Meckbach, Centro Atomico, Bariloche, Argentina are to take part in our program this coming year.

Plans

1. Complete and commission MEIBE II.
2. Continue some studies of dissociative recombination looking at the effect of vibrational excitation on the cross-section and upon H^* and $H^+ - H^-$ formation.
3. Attempt to develop an electron energy loss method of studying e-ion excitation.
4. Measure absolutely He^+ (2s and 2p) excitation and H^- and D^- detachment cross-sections.
5. Examine some systems with MEIBE I which are prototypes of dielectronic recombination with HeH^+ , HeD^+ , He_2^+
6. Examine dielectronic recombination of C^+ and Mg^+ .
7. Continue charge transfer into the continuum studies of several relevant systems.

Milestones

1. Complete MEIBE II—June 1979.
2. Complete dissociative recombination studies dealing with vibrational excitation of $H_2^+(v)$ —January 1979.
3. Complete measurements of $H^+ + H^-$ and $H^* + H$ cross sections—March 1979.
4. Complete prototype dielectronic recombination cross section measurements of He_2^+ , HeH^+ , etc.—March 1979.
5. Complete calibration of 304Å radiation detectors—December 1978.
6. Measure H^- -e detachment cross sections—May 1979.
7. Complete first attempt at dielectronic recombination cross section measurements for Mg^+ and/or C^+ with MEIBE I—July 1979.

Graduate Students (% DOE support, degree)

K.C.R. Chiu (33, Ph.D.); V. d'Angelo (33, MSc.); A. Sen (33, Ph.D.); P. Mul (100, Ph.D.)

Graduates

None

Other Professional Staff

None

Major Recent Publications

J. B. A. Mitchell and J. Wm. McGowan, The Dissociative Recombination of $\text{CH}^+ \text{X } ^1\Sigma^+ (v=0)$, The Astrophysical Journal 222, L77, 1978.

J. Wm. McGowan, P. M. Mul, V. S. D'Angelo, J. B. A. Mitchell, P. DeFrance and H. R. Froelich, Energy Dependence of the Cross Section for Dissociative Recombination for Electron Energies < 0.08 eV, Accepted for Publication, Phys. Rev. Letters.

P. M. Mul, J. B. A. Mitchell, V. S. D'Angelo, P. DeFrance, J. Wm. McGowan and H. R. Froelich, Merged Electron-Ion Beam Studies of Dissociative Recombination IV—A Study of the Methane Group $\text{CH}^+ \dots \text{CH}_5^+$, Submitted to J. Phys. B.

P. M. Mul, J. Wm. McGowan, Dissociative Recombination of N_2H^+ and N_2D^+ , Submitted to The Astrophysical Journal (Letters).

J. Wm. McGowan, Electron-Ion Collision Studies (a review), Proceedings of the VI International Conference on Atomic Physics, Riga.

ADVANCED SUPERCONDUCTING MATERIALS (S/C) PROGRAM

Some mainline and alternate fusion concepts will require very high magnetic fields. In order to make these systems energy efficient, superconducting magnets will be needed. Materials which are both ductile and capable of these high fields (i.e., $\geq 12\text{T}$) are not present. To meet this need an Advanced Superconducting Materials Program was initiated.

This program consists of two parts. The first is a search for new and/or advanced materials and the detailed investigation of their mechanical and superconducting properties. The second involves improved processing and fabrication techniques to upgrade the performance of existing materials such as Nb_3Sn .

Advanced Superconducting Materials Program

Significant Events

- **Demonstration that fine fiber multifilamentary Nb₃Sn superconductors had better critical current density and field characteristics than commercial wire. This is important for the attainment of high fields and the maintenance of superconductivity.**
- **New processing techniques have been found which enhance the mechanical properties of Nb₃Sn which otherwise would be extremely brittle.**

Project

Development of a Ductile 15 Tesla Superconductor
FY78 \$330K FY79 \$330K

Purpose

To develop a strong, relatively ductile superconductor with the ability to carry 10^5 amps/cm² at 15 T magnetic field and to withstand at least 2% strain without significant degradation of these capabilities.

Approach

Several interdependent avenues of approach are used:

1. The development of in situ composites of compound superconductors in normal matrices by rapid quenching of melts and wire drawing, and other methods which result in similar microstructures.
2. The development of superior composite microgeometries by analysis of degradation mechanisms in currently manufactured multifilamentary bronze-matrix Nb₃Sn composites; development of model composites, as experimental tests and as prototypes of superior materials.
3. The development and testing of fatigue models to predict performance of superconducting composites under cyclic stresses typical of fusion devices.
4. To characterize and analyze the mechanical and superconducting properties of compound superconductors in order to develop an analytical base for approach #2 and to identify compounds with superior mechanical properties. This includes the lattice dynamical basis for mechanical and superconducting properties.

Progress in FY78

1. A series of Nb₃Sn-based multifilamentary composites were fabricated to comprise a data matrix, with superconductor volume fraction and fibre size as the variables. The finest fibre sizes, 0.125μ, produced very strong materials which tolerated strains up to 1.5% without degradation, on the initial (presumably non-optimal) trials.
2. A fatigue model for multifilamentary composite failure was developed based on the assumption of elastic fibres in a ductile matrix. The model can predict; the endurance limit, the number of cycles to cause failure, or the number to assure that all subsequent strains are elastic, i.e., the shakedown limit.

3. In situ multifilamentary wires with improved high field properties have been developed. An overall critical current density greater than 10^4 A/cm³ has been achieved at 14 Tesla for a Cu-36 wt % Nb-20 wt % Sn material. The results are equal to or better than the best-reported commercial multifilamentary Nb₃Sn materials.
4. The mechanical properties of in situ superconducting wires have been measured. For good samples, no degradation of critical current J_c is observed for stresses σ up to 700 MPa (~ 100 ksi) which corresponds to strains of approximately 1½ to 2%.
5. Stress-strain data and cyclic stress data are consistent with the prestress model for composite materials in which it is assumed that the bronze matrix produces a compressive stress on the superconducting filaments in the in situ materials. Evidence for partial relief of the prestress by cyclic stress treatment has been observed.
6. Using powder metallurgy techniques, Nb₃Sn multifilamentary wires have been prepared using cold extrusion. The J_c values obtained are superior to all previous powder approaches (which used hot extrusion powder metallurgy) splat cooling, or the highest values of Tsuei using the in situ technique, and in fact are comparable at high fields to commercial multifilamentary material.
7. Characterization of the C-15 Laves phase ZrV₂ alloy indicated that it does not undergo a lattice transformation. Arc-cast ZrV₂ (prepared from powder constituents) exhibited breaking stress at least as high as values obtained from carefully fabricated A-15 V₃Ga, indicating that the C-15 compounds may, in fact, have superior mechanical properties.

Plans

1. The maximization of the very fine fibre multifilamentary conductors with respect to J_c and mechanical properties. Analysis of other factors (microgeometry, internal stresses, etc.) which can further improve properties.
2. The development of a quantitative fatigue model which predicts the behavior of multifilamentary superconductors under stress and especially cyclic stress. The model will allow for the development of guidelines for the fabrication of practical superconducting materials.
3. The maximization of the in situ technique so as to improve J_c and the mechanical properties. A comparison between the very fine fibre and in situ technique will be made. The fatigue model will be developed for in situ wires. In situ ternary superconductor with improved H_{c2} and J_c will be fabricated.
4. Using continuous casting techniques the in situ process will be scaled-up. First a semi-continuous casting process will be used to increase the casting quantities by a factor of 10. The next phase will involve evaluation of the design and the development of a continuous casting process as a prototype for commercial development.
5. The in situ technique will be extended to other A-15 and other high field superconductors.

6. Application of our powder metallurgy techniques to materials for which the in situ or other approaches are not feasible. Specimens of the Chevrel-phase materials as well as Nb_3Al will be prepared and developed.
7. Single crystals of the A-15 and C-15 will be characterized fully as to the properties which affect the mechanical behavior of superconductors, and the question of whether or not the C-15's mechanical properties are superior should be answered.
8. A scale-up technology for the external diffusion multifilamentary technique will be developed, in order to facilitate large scale ultrafine fibre manufacture and significantly reduce the cost of conventional multifilamentary fabrication.

Milestones

1. The quantitative assessment of the role of volume fraction and fibre size on the critical current J_c and mechanical properties of continuous fibre multifilamentary superconductors; by finishing the testing of the "matrix"—February 1979.
2. The experimental testing of the fatigue model with respect to continuous and in situ materials—February 1979.
3. The manufacture of a continuous Nb_3Sn ultrafine multifilamentary composite which has a high J_c and whose properties do not degrade under strains as high as $\sim 2\%$ —June 1979.
4. Maximization of J_c for in situ materials with high current density at 15 Tesla—June 1979.
5. Modification of the matrix for in situ materials to further improve the mechanical properties—September 1979.
6. Quantitative stress-strain and cyclic stress-strain data and analysis for continuous and in situ materials—April 1979.
7. Fabrication of in situ ternary alloys—September 1979.
8. Using semi-continuous casting, the scale-up of specimens from 30 g to 200-300 g—September 1979.
9. Development of high current density Nb-Sn-In alloys—April 1979.
10. Preparation of Chevrel-phase wires using cold extrusion powder metallurgy techniques—September 1979.
11. Growth and characterization of single crystal A-15 and C-15 materials—May 1979.
12. A preliminary computer model for microscopic imperfections and local inhomogeneities and their relation to the mechanical properties will be developed—June 1979.
13. Initial results on external diffusion scale-up technology—March 1979.
14. Complete the strength assessment of Nb_3Ge sputtered films—November 1978.

Graduate Students

1. Project students (% of DOE support, degree, years to complete):
J. A. Gregory (100, Ph.D., 1); S. F. Cogan (100, Ph.D., 2); V. Diadiuk (0, Ph.D., graduated 1978); T. Lcc (0, Ph.D., 3).
2. Graduated during the past three years:
V. Diadiuk (see above).

FUSION PLASMA RESEARCH FACILITY (FPRF) PROGRAM

Project

TEXT

K. Gentle

TEC \$7,900K

Purpose

The TEXT device provides a facility for the MFE program to conduct research and development projects on a plasma that is typical of major confinement experiments. The facility will be available to users from throughout the fusion community including universities, industry and government laboratories. The objectives for TEXT are complimentary to the tokamaks at PPPL, ORNL, and GA and consist of important fusion development projects that cannot be undertaken on a timely basis by the main-line programs. In particular, the objectives of projects on TEXT are:

1. Provide atomic and molecular data of impurity ions in tokamaks required for analysis of plasma heating and cooling mechanisms, surface interactions and diagnostics.
2. Test, evaluate, and standardize existing diagnostics and develop new diagnostic techniques.
3. Serve as a facility to test new ideas in order to improve plasma heating, equilibrium, and stability.
4. Provide quantitative tests of theoretical plasma models, particularly large computer codes.
5. Train scientists directly on confinement devices.

Background

One of the primary recommendations of the Overview Panel in "The 1974 Review of the Research Program," ERDA-39, was the establishment of medium-scale confinement devices as research facilities to accommodate user groups from all sectors of the MFE program. In December 1974 an Ad Hoc Committee on Fusion Plasma Research Facilities was formed to further evaluate the need for and to determine characteristics of this kind of device. A report of the Committee, ERDA-106, concluded that one or more Fusion Plasma Research Facilities (FPRF) should be established consisting primarily of high duty cycle, medium-scale, research-oriented confinement devices capable of producing plasmas with near-thermonuclear parameters. A tokamak device was accorded the highest priority for the first FPRF.

The University of Texas submitted a proposal to build an FPRF in July 1976. A technical panel was convened by ERDA at Austin, Texas, to review the proposal in August 1976. A preliminary report was made by the panel at that time and a final report was submitted to ERDA in early October 1976 in which they concluded:

- The facility is a "well designed plasma device capable of meeting the scientific objectives presented in ERDA Report 106" (the committee report).
- A user's advisory committee should be set up immediately.

Plans

TEXT is designed with a major radius of 100 cm, limiter radius of 28 cm, magnetic field of 3T, pulse length of 300 ms, and a repetition rate of a shot each two minutes. Estimates of the plasma characteristics suggest a density of 3×10^{13} , average electron temperature of a kilovolt, and a central ion temperature of similar magnitude. These properties, together with good geometric access to the plasma and the provisions of complete diagnostics and computer data acquisition, will make an excellent research facility.

TEXT will be built in laboratory space at the University of Texas at Austin and operated by the University. The University of Texas Fusion Research Center will manage and administer the project with the assistance of University business components.

Milestones

1. Sign principal contract for site preparation—November 1978.
2. Receive rectifier for toroidal field—April 1979.
3. Complete fabrication of tokamak assembly for shipping to UT—May 1979.
4. Distribute draft of Handbook for potential users—November 1979.
5. Complete Site Construction—November 1978.
6. Begin TEXT Installation—January 1979.
7. Complete Installation of TEXT—September 1979.

Comments

The TEXT facility will be available to users from other installations besides the University of Texas. This permits specialized experimental groups at universities and laboratories that are expert in, say, particular diagnostic techniques or atomic data measurements to have ready access to a fusion plasma so as to apply their expertise to the MFE program. A user's committee will be formed in the immediate future including representatives from ERDA, Texas, and potential user organizations. The committee will present the needs of various user specialties to Texas in time to affect design choices. The committee will also provide prospective users with information and assistance, help DMFE/APP plan a coordinated development program, and eventually assist in scheduling experiments on the device.