FusionCanada

Bulletin of the National Fusion Program

Issue 20, March 1993

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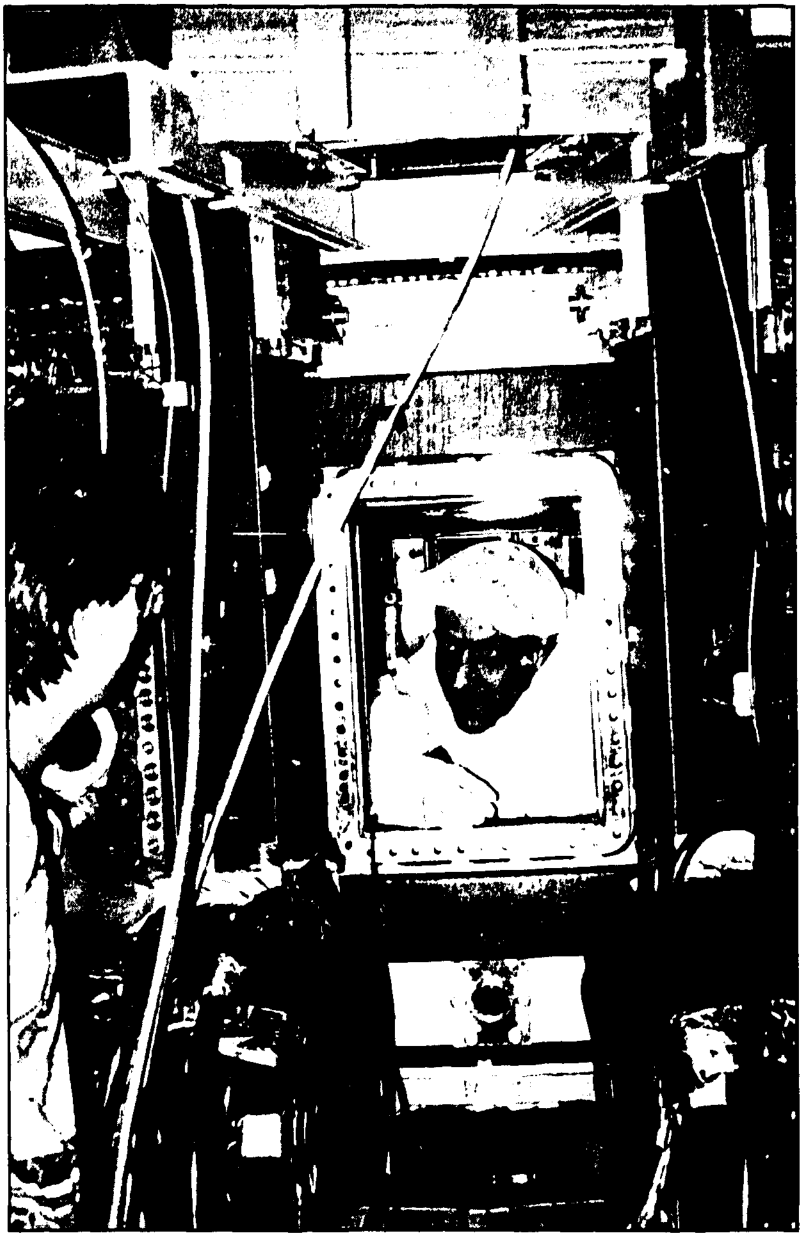
ISSN 0835-488X

TdeV



From inside TdeV, Serge Brousseau, Specialist Welder, discusses tokamak modifications with a colleague during the winter maintenance shutdown. Mr. Brousseau performs most of the mechanical modifications inside TdeV.

CFFTP - CANADIAN FUSION FUELS TECHNOLOGY PROJECT

Industrial Impact of CFFTP

A study of the industrial impact of the Canadian Fusion Fuels Technology Project (CFFTP) was completed in March this year by a Toronto consulting group and three senior external advisors.

In 1991, a comprehensive and detailed evaluation of Canada's federal energy R&D programs was performed by the ARA Consulting Group, Inc. for the Government of Canada. This study, the *ARA Study,* reviewed all the energy R&D programs funded by Canada's Panel on Energy Research and Development (PERD), including fusion energy. It was the largest science and technology review ever conducted in Canada. The response of study participants to the National Fusion Program (NFP) was very positive. They concluded that the NFP is a well designed R&D program, justifiable on economic and scientific grounds, and its technology focus maximizes current Canadian research and industrial capability. The study endorsed the NFP's decision to focus on tritium technologies and aspects of tokamak design, as being an appropriate way to maximize the benefit from a modest fusion program. The NFP program, including the key research centres CFFTP and Centre canadien de fusion magnétique (CCFM) was endorsed as "an excellent model of co-opera-

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CFFTP - CANADIAN FUSION FUELS TECHNOLOGY PROJECT

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tive and innovative government/industry international R&D work". It was considered to be of high relevance to the world fusion effort.

Because industrial involvement in Canada's fusion programs is essential to Canada's fusion strategy, one of the recommendations made by the *ARA Study* was that the industrial impact of the fusion program be reviewed independently and in further detail.

Acting on this recommendation, NFP officials in 1991 contracted with the Science Council of Canada to conduct an appropriate review of CFFTP and CCFM. The Impact Group in conjunction with NGL Consulting were subcontracted by the Science Council to conduct the research component of the study. The Science Council was discontinued in 1992, before the project could be completed. NFP subsequently re-engaged The Impact Group and NGL Consulting to complete the elements of the study dealing with the industrial impact of CFFTP. The project team established an independent Expert Review Panel to oversee the CFFTP study. Three distinguished individuals with extensive experience in industrial and academic settings agreed to join the Panel:

- Dr. Philip A. Lapp, winner of the Canadian Council of Professional Engineers' Gold Medal.
- Dr. John Elliott, a winner of the Canadian Advanced Technology Association's "Person of the Year" award.
- Prof. Barry French, a distinguished researcher and lecturer and technology entrepreneur.

The study team surveyed and interviewed the companies and universities associated with CFFTP, and examined CFFTP's objectives and administration and its links and contracts with industry and universities.

Industry involvement with CFFTP, the study found, has resulted in Canadian companies supplying a total of about $17 million in fusion related products and services from 1987-1992. Of this, products comprised about $11 million (65%), and services such as engineering design about $6 million (35%). Export sales of products and services together accounted for more than $10 million of the $17 million total. Through CFFTP, Canadian industry is currently supplying about $3 million annually in fusion technology and expertise to the world fusion community.

The study concluded that CFFTP broadly meets its goals and objectives. CFFTP is supplying fusion and related technologies to world fusion projects, and has achieved high international recognition. Through its technology development programs and export contracts, CFFTP has supported and developed domestic research facilities (primarily public sector or university laboratories). Through CFFTP programs, industrial fusion capabilities have increased, commensurate with the amount of money being spent in industry. By providing international marketing and by assembling groups of companies to compete for fusion projects, CFFTP is bringing to Canadian companies work which they otherwise would not have obtained. CFFTP is also actively working at technology transfer, although there is as yet little direct evidence of applications outside fusion.

The major concerns of the study were related to the scope and balance of CFFTP's activities. Specifically, it expressed reservations about the scope of CFFTP's activities, suggesting that CFFTP might be attempting too much with limited resources. While the technologies might have a high degree of technical merit, funds are not sufficient to develop them all into products. If CFFTP's funding partners want the project to be more industry-oriented than the R&D focus of the past ten years, then CFFTP should identify a limited set of enabling or core technologies, and should focus sufficient resources to develop products based on those technologies.

Overall, the study concluded that the CFFTP program is well thought out, and in many respects a model of its kind.

More information: Ann Palen, CFFTP, (416) 855-4704 or Gil Phillips, Manager - Fusion Fuels, NFP (see Contact Data).

CENTRE CANADIEN DE FUSION MAGNÉTIQUE

TdeV-M

Upgrade Planning for TdeV

Fusion research tokamaks like TdeV must undergo a constant process of upgrading and equipment addition during the course of their lives. As fusion reactor technology and physics advance, the research tokamak's configuration and operating conditions need upgrading so that it can continue delivering new data for fusion reactor design. In particular, research tokamaks need to simulate as closely as possible the conditions - such as plasma density and divertor heat loads - expected to be present in a fully igniting fusion reactor.

CCFM staff began in 1992 to examine the potential needs for the configuration of TdeV for to perform CT research including plasma heating and CT-driven plasma current drive on STOR-M *(see FusionCanada No. 19, December 1992).*

Saskatchewan's work is well regarded internationally, and Prof. Hirose and colleagues collaborate actively with fusion centres abroad. Among their collaborations are those with:

Prof. O. Mitarai (Kumamoto Institute of Technology, Japan): AC tokamak operation and tokamak reactor modelling.
Prof. O. Ishihara (Texas Tech. University, USA): Strong plasma turbulence theory and anomalous transport.
Prof. J. Weiland (Chalmers Institute of Technology, Sweden): Drift-type instabilities in tokamaks.

Visitors to the Saskatchewan laboratory in 1992 included A. Smolyakov of the Kurchatov Institute (Russia) and K. Jain of India's Plasma Research Laboratory.

STOR-M Tokamak Upgrade

The main objectives of the STOR-M upgrade being funded by NFP are to increase the tokamak's toroidal magnetic field to 2 Tesla, from the present 1 Tesla, and increase plasma current to 100-150 kA from the previous 50 kA level. The upgraded STOR-M will operate with better confined, hotter and denser plasmas than before, and so help ensure that future experiments (see below) will remain relevant to modern fusion reactor designs. The upgrade includes fitting of new magnet coils and support structures.

STOR-M Experimental Program

After completing the STOR-M upgrade in autumn this year, planned experiments include:

- Alternating current tokamak operation, as demonstrated some years ago at Saskatchewan, and more recently on JET.
- Compact toroid injection.
- Radiofrequency plasma heating, exploring the uninvestigated helicon mode in the 10-50 MHz frequency band.
- Continued investigation of anomalous heat transport in tokamaks.

It continues to vex tokamak researchers that heat loss from tokamak plasmas is in reality considerably more rapid than heat loss predicted by present theories of plasma behaviour. The additional - and undesirable - heat loss, not yet understood, is generally referred to as *anomalous heat transport*. Saskatchewan has a strong continuing interest in this field, and part of the NFP funding will be devoted to testing new theories on STOR-M, developed by Prof. Hirose, that appear to shed light on the phenomenon. The new theories - which suggest the presence of high frequency skin-size electromagnetic drift modes in the plasma core - appear capable of reproducing temperature profiles recorded experimentally on JET and TFTR.

More information from Prof. Akira Hirose, Physics Dept., University of Saskatchewan, (306) 966-6414, Fax (306) 966-6400, or from Charles Daughney, NFP (see Contact Data).

INRS ÉNERGIE ET MATERIAUX

Deuterium Behaviour in Beryllium

New high temperature data

The behaviour of deuterium in beryllium, at high D/Be concentrations (up to 20%) and high temperatures, is being investigated at INRS Énergie et Materiaux, a research institute of the Université du Québec and a partner in CCFM. Indications are that under the conditions of the experiment, deuterium migration in beryllium is significantly more rapid than shown in published data, at temperatures up to beryllium's melting point (1,551 °K). Since beryllium is a possible coating material for plasma-facing fusion reactor components, high temperature data on deuterium migration in beryllium is valuable.

Under the program direction of Bernard Terreault, Danielle Kéroack has so far measured deuterium desorption over the range of 2-20 atom % deuterium in beryllium. Deuterium is implanted with an ion beam and desorbed with variable energy short (30 nanosecond) laser pulses. Surface temperatures up to beryllium's melting point can be reached. The rapid heating is important so that one can measure diffusion in isolation, after the deuterium is released from trapping sites in the beryllium lattice. To recover detrapping energies, detrapping coefficients and diffusion coefficients for the implanted deuterium, the measured deuterium release rates are interpreted with the DTRLAS code developed at INRS by Prof. Terreault.

Results

Second order detrapping, with a detrapping energy of 1.6 eV appears to be the limiting factor in desorption of deuterium from the beryllium samples. At deuterium in beryllium loadings up to 12%, desorption is fitted by:

Detrapping coefficient $v = 10^{-8} \exp(-1.60 \text{ eV/molecule}/kT) \text{ cm}^3.\text{s}^{-1}$

Diffusion coefficient $D = 4\times10^{-4} \exp(-0.32 \text{ eV}/kT) \text{ cm}^2.\text{s}^{-1}$

The large apparent diffusion coefficient is believed to be connected with the high deuterium concentrations and irradiation damage caused by ion beam implantation of high deuterium doses.

INRS will research deuterium behaviour in other fusion materials, including pure and doped carbons, carbon-carbon compos-

Divertor pumping. With all four divertor cryopumps operating, systematically explore pumping speeds and characteristics for helium, neon, nitrogen and hydrogen and other impurities including molecular gases.
Detailed divertor region observations. These are to include bolometry measurements of divertor radiation, as well as visible spectroscopy and TV camera observation techniques. Embedded probes in the divertor plates will monitor current profiles onto the plates and ion saturation current. Divertor plate heat flux measurements will be done under increased biasing, using techniques including infra-red divertor plate optical measurements. Embedded thermocouples will be installed in August.
Compact Toroid fuelling. Exploration of required injection velocities. Compact torus magnetic reconnection behaviour studies. Effects on plasma density profiles and decay of CT-induced density changes.
Diagnostics. Commissioning of the US neutral thallium beam for edge potential and density measurements, now mounted on TdeV. The fast-scanning retracting Langmuir probe, purchased from University of Texas, and modified locally for plasma biasing studies, will enter service for plasma edge scanning. Continue refining operation of the laser polarimeter, for measuring current density profiles.
Inject lithium pellets via MIT pellet injector into TdeV, and characterize vacuum chamber wall deposits. This experiment is a collaboration with Princeton Plasma Physics Laboratory, to gather data for the forthcoming TFTR deuterium-tritium operations phase.

More information from Brian Gregory, CCFM, (514) 652-8729.

UNIVERSITY OF SASKATCHEWAN

NFP Research Funding for Saskatchewan Plasma Physics Group

The National Fusion Program recently awarded a new three-year research grant totalling $210,000 to University of Saskatchewan Plasma Physics group. NFP granted the new research funds primarily to help upgrade Saskatchewan's STOR-M tokamak, and to fund research into anomalous heat loss mechanisms in tokamak plasmas. The Saskatchewan group receives year-to-year operational funding from Canada's Natural Sciences and Engineering Research Council (NSERC).

The Plasma Physics Laboratory, founded by Harvey Skarsgard in the 1960s, has a long history of basic plasma physics research, and a reputation for high-quality experiments and theory development. The tokamak program was started by Akira Hirose in 1984 with a small tokamak, STOR-1M, a predecessor to today's STOR-M. The consistent research output by the two researchers and their associates has resulted in the group's work being funded by NSERC for many years. Operating as an independent fusion research centre, the Saskatchewan group has attracted support from the National Fusion Program and its two key research sites, Centre canadien de fusion magnétique (CCFM) and the Canadian Fusion Fuels Technology Project (CFFTP). In addition to its average $150,000 annual funding from NSERC, the Saskatchewan group has attracted $1.2 million in project funding in the last two years. This includes the recent NFP research contract of $210,000, an NSERC Strategic Grant and a research contract from CFFTP. The $650,000 CFFTP contract, starting in 1991, was for engineering, building and testing a compact toroid (CT) fueller for installation on the TdeV tokamak at CCFM. As a result of that success, NSERC awarded the Strategic Grant of $300,000 for the design and building of a second Saskatchewan CT fueller, *USCTI,*

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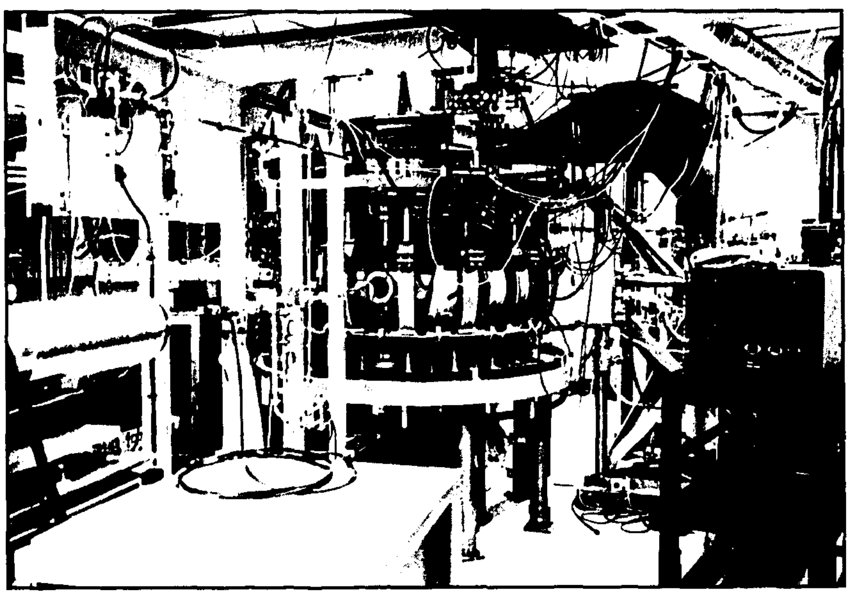


The STOR-M tokamak at University of Saskatchewan. The large curved duct (upper right background) is the vacuum pumping duct for a hydrogen neutral beam plasma probe.

work in 1998 and beyond. The present TdeV divertor configuration, with lower hybrid-frequency current drive (LHCD), will be yielding important results for several years, as CCFM staff explore uncharted fields such as divertor operation with LHCD at high energy density and compact toroid fuel injection. Nonetheless, it can be foreseen that beyond about 1998, when fusion reactor design has advanced well beyond today's understanding, TdeV in its presently equipped form will become less able to perform the fusion research needed at that time.

CCFM staff believe that TdeV will require upgrading to provide hotter and denser plasmas, and higher divertor power and particle flux loads. Since major machine upgrades require several years to design and accomplish, it is appropriate to start planning TdeV's future configuration at this time. Upgrade plans are progressing under the working name TdeV-M.

Any TdeV upgrade option must be a balance between available funds and the optimization of scientific and technical enhancements in selected areas. The scientific focus of CCFM - narrow or broad, and the selection of research topics - is an important part of the planning process.

Bearing these factors in mind, CCFM has been considering a wide range of possible upgrading options for TdeV. The result is that a possible equipment plan and a tentative schedule for progressive major upgrading of TdeV is in the process of being compiled.

TdeV's toroidal field could be improved from 1.5 Tesla to about 2 Tesla for short pulses. To permit higher plasma currents, and flexible single-null operation, two new power supplies would be needed. Higher powered non-inductive current drive and auxiliary heating capability is also being considered, in addition to the 1 MW LHCD system currently being completed on TdeV.

Before the year 2,000, further major machine changes could provide significant increases in plasma density and temperature, and plasma current. Such changes might include a new, larger vacuum vessel, and replacement of poloidal magnet coils to allow plasma currents of 500 kA or more, with a reactor-relevant single null divertor geometry. Long pulse operation (about 25 seconds or better) would be retained at the lower field of 1.5 Tesla and at lower plasma currents. The mission of such a machine would be continuation of divertor technology and physics research at increased power levels relevant to fusion reactors.

During 1993, work will intensify on examinations of the long range CCFM scientific program, TdeV upgrade timing and cost vs. scientific benefit. International peer groups including CCFM's Scientific Advisory Committee will be consulted about TdeV-M, as they were about the design and mission of the LHCD system.

More information from Réal Décoste, CCFM, (514) 652-8715.

CENTRE CANADIEN DE FUSION MAGNÉTIQUE

CCFM Update

TdeV News & Scientific Program

The TdeV tokamak returned to service in early February after a four-month refit and maintenance shutdown. Plasma biasing and helium pumping trials resumed in March, after TdeV was recommissioned during February.

As FusionCanada went to press in mid-April, CCFM researchers had conducted the first full scale helium "ash" divertor pumping tests, and operated TdeV with improved plasma biasing voltages in divertor mode, in the range - 250 to + 450 volts. Helium pumping tests, assisted by negative plasma biasing, gave excellent initial results. With TdeV in divertor mode, the pumping time constant was measured as being 150 milliseconds for helium pumping. This compares with a TdeV particle confinement time of 10 milliseconds; i.e. a ratio of about 15:1. While TdeV is not a reactor-size tokamak, this ratio is near the value of the 10:1 ratio of pumping time constant vs. plasma particle confinement time that fusion reactors are expected to require. While CCFM workers recognize that these are early results, at modest plasma densities and without H-mode, it is believed they represent proof of principle that helium exhaust from plasmas by cryopumping through the divertors is feasible. These are the first known demonstrations of tokamak helium pumping via divertors.

TdeV will be shut down during May for minor divertor modifications and installation of some radiofrequency LHCD equipment. A further experimental period will then extend from the end of May to the beginning of August.

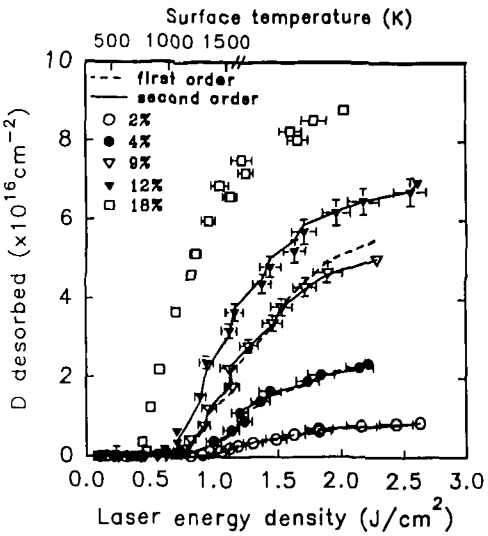
Scientific Program: March - August

The main experiments planned for this period are:

Biasing trials. Continue biasing trials at voltages as high as possible, primarily to extend and confirm observations already made about biasing effects, including saturation of some parameters at higher biasing voltages.

ites, and titanium carbide. The work is funded by the Natural Sciences and Engineering Research Council.

More information from Danielle Kéroack, INRS, (514) 449-8161, Fax (514) 449-8102, or Bernard Terreault (514) 449-8111.



Deuterium desorption profiles for INRS deuterium migration experiments. Each curve represents, for a particular concentrations of deuterium in beryllium, deuterium released at a particular on-sample laser surface energy density. As the top axis shows, surface melting occurs beyond about 1.2 $J.cm^{-2}$.

NEWS NOTES

CCFM 1992 Annual Report

This report is now available; it includes a review of 1992 research results. Contact the CCFM Secretariat to request copies. (see Contact Data).

IAEA Meeting in Toronto: Developments in Fusion Safety

For the National Fusion Program, CFFTP will host the IAEA Technical Committee Meeting on "Developments in Fusion Safety", June 7-11, 1993 at the Delta Chelsea Inn, Toronto, Ontario. *Contact Gary Vivian, CFFTP, (416) 855-4733, Fax (416) 823-8020.*

Editorial Office: Change of Address

The FusionCanada editorial office, operated by Macphee Technical Corporation, has moved to another address, effective May 1, 1993. Please see Contact Data for new address and telephone and fax numbers, and update your files.

National Fusion Program

Director, *Dr. David P. Jackson*

The National Fusion Program (NFP) coordinates and supports fusion development in Canada. NFP was established to develop Canadian fusion capability, in industry and in research and development centres. NFP develops international collaboration agreements, and assists Canadian fusion centres to participate in foreign and international projects.

NFP is managed for Canada by Atomic Energy of Canada Limited. Federal funding is provided by the Department of Energy, Mines and Resources through the Panel on Energy Research and Development.

'FusionCanada' Bulletin

'FusionCanada' is available free to interested persons. It is published four times each year, in French and English editions. Write to NFP Office, 'Bulletin Subscriptions' (see Contact Data). Please specify French or English edition, (or both if desired), and number of copies if several are required.

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Ce Bulletin est aussi disponible en français

Printed in Canada on recycled paper