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ITER

Canada-ITER Contributions

Canadian R&D contributions to ITER in a number of areas are now defined. Staff attachments to ITER and NET have been agreed, and some have begun already. Canadian contributions to ITER are made through the European Community.

Contributions by Canadian Fusion Fuels Technology Project (CFFTP). The European Community and the ITER Council have agreed that design and R&D contributions in the following specialized topics will benefit ITER:

Design contribution topics:
- Tritium systems.
- Maintenance and assembly.
- Breeder blanket design.

R&D contributions are to be made in three of the specific topics identified by the ITER team:
- Aqueous lithium salt chemistry.
- Erosion behaviour of modified graphite in first wall applications.
- Fuel systems (fuel handling, isotope separation, tritium extraction, fuel purification).

Robert Stasko of CFFTP is the Canadian representative on the European Community ITER team, at the 1989 ITER summer work session at Garching, FRG.

CCFM Contributions. The scope and exact nature of contributions by Centre canadien de fusion magnétique (CCFM) are currently being formalized. Arrangements may include experimental and modelling work in tokamak plasma impurity transport, and tokamak electrical power system design. The attachment of Guenther and Horst Pacher to NET by CCFM will aid the definition of further CCFM-ITER cooperation (see *Staff Attachments to NET*).

CFFTP-NET

NET Fuel Processing Loop.

A detailed design for the NET Fuel Processing loop is being performed by Ontario Hydro, under a contract from the Canadian Fusion Fuels Technology Project (CFFTP). The finished design, to be completed by mid-1990, will be a candidate for the NET Fuel Processing loop reference design.

The system's specification requires processing of up to 150 moles (about 750 grams) per hour of torus exhaust gases and other waste streams, and the production of a purified deuterium-tritium stream ready for feeding to an isotope separation system.

The design concept uses two beds of 'molecular sieve', cooled to liquid nitrogen temperatures, to remove molecular impurities from the raw torus exhaust stream. While one bed is processing exhaust gases, the other will be regenerated. Impurities to be removed include tritiated and tritium-free forms of ammonia, methane and water vapour. Deuterium and tritium will be only slightly absorbed into the 'molecular sieve'; most of the deuterium and tritium will pass directly through the beds to an isotope separation system. A maximum of 150 grams of tritium, in various chemical forms, will be absorbed in each bed. 'Molecular sieve' is a trade name for the mineral zeolite (alumino-silicates). Zeolite has the property of trapping molecules of certain sizes in its pores, while other molecules escape adsorption and pass by.

The beds will be regenerated by heating to drive off collected impurities, which will then be oxidised to produce tritiated water. An electrolysis cell will process the tritiated water, so that deuterium and tritium can be returned for re-use in the fuelling system.

Project Manager for the design is Sav Sood of Ontario Hydro. Dr. Sood is attached to NET between August 1–September 5, to work on NET fuel processing systems and fuel system problems common to NET and ITER.

Further information: Otto Kveton, CFFTP, or Sav Sood, Ontario Hydro (after Sept. 20) (416) 592-5501.

29-01

INTERNATIONAL

3RD Canada-Europe Bilateral Meeting

Future Directions

The heads of the Canadian and European Community (EC) fusion programs met June 15 to review Canada-Europe fusion collaboration, and to discuss future work. David Jackson (Director—National Fusion Program) and Charles Maisonnier (Director—EC Fusion Program), held their discussions at the Next European Torus (NET) site in Garching, FRG, assisted by technical leaders from each program.

It was agreed at the meeting that events in the next three years would have a significant impact on both the Canadian and European programs. In November 1990, the Concept Definition Phase of ITER is scheduled for completion, and an international decision will then be required on whether and how to continue ITER work, towards its detailed design and actual construction. Canada has been contributing to ITER conceptual design activities through the European Community. In view of Canada's commitment to ITER contributions, the project's future will be a factor in steering Canadian fusion work beyond 1990. The outcome of this decision will also be important in determining the course of Europe's NET project. The NET team is working on the pre-design of Europe's next major machine after JET, and as such is an important focal point for ITER collaboration. Since Canadian fusion workers are well integrated into the NET project, the future course of NET work is also of importance to Canada.

In March 1991, the current Canada-EC Memorandum of Understanding (MoU) on fusion collaboration expires. The Canadian and European fusion programs are both favourably disposed toward entering into another collaboration agreement. The scope and nature of this agreement will be important to both parties, as will the budget commitments to fusion in Canada and Europe.

The meeting reviewed collaborations on ITER, the Joint European Torus (JET) and the Next European Torus (NET), as well as collaborations on other technical matters. Each party expressed satisfaction with the technical quality and activity level of cooperative work to date, and expressed the desire to continue collaborative work.

Present at the meeting were:
Canada: D.P. Jackson; W.J. Holtslander (NFP); D.P. Dautovich (CFFTP); R. Bolton (CCFM); A.G. Brace (NFP-Brussels).
Europe: C. Maisonnier; J. Darvas; E. Canobbio; H. Donoghue (EC); M. Huget (JET); R. Toschi (NET).

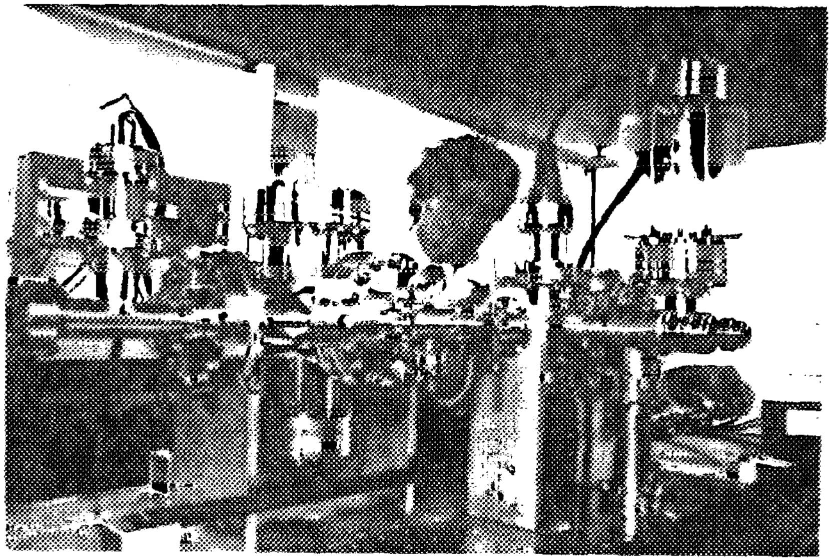
For the last two years, A.G. (Tony) Brace has had special responsibility for developing Canada-EC relations in fusion collaboration, and for that purpose has been attached to the Canadian Mission to the EC in Brussels since June 1987. He returned to Canada in July this year, and will continue with the same special responsibility. Mr. Brace is Comptroller of the Design and Construction Branch for Ontario Hydro. His work in Canada-EC relations is supported by Ontario Hydro, the National Fusion Program and CFFTP.

CCFM NET

Staff Attachments to NET

Guenther Pacher
Horst Pacher

Guenther Pacher and Horst Pacher of CCFM begin long-term attachments on September 1 at the Next European Torus (NET), seconded to NET from Centre



Glovebox interior in UTIAS tritium laboratory.

canadien de fusion magnétique (CCFM), Varennes, Québec. They have joined the NET physics team, to work on problems common to NET and ITER. Their work will include edge plasma physics and tokamak operating scenarios such as disruption control.

Guenther Pacher is employed by Hydro-Québec as a research scientist and Horst Pacher is a professor at INRS-Énergie. Until their attachment to NET, Guenther was CCFM Technical Coordinator, mainly responsible for tokamak operations. Horst was CCFM Scientific Coordinator, in charge of establishing and coordinating the scientific program. At INRS-Énergie, he was also responsible for coordinating magnetic confinement studies. Both will remain CCFM staff members during the term of their attachment to NET.

Both men came to Varennes in 1982 to join the Tokamak de Varennes project at the start of its construction phase, after working on the WEGA fusion machine (joint project of IPP Garching and CEN Grenoble) for several years. Each has contributed greatly to the current success of Tokamak de Varennes operations and the CCFM experimental program.

CCFM—Centre canadien de fusion magnétique

New Information from Tokamak de Varennes

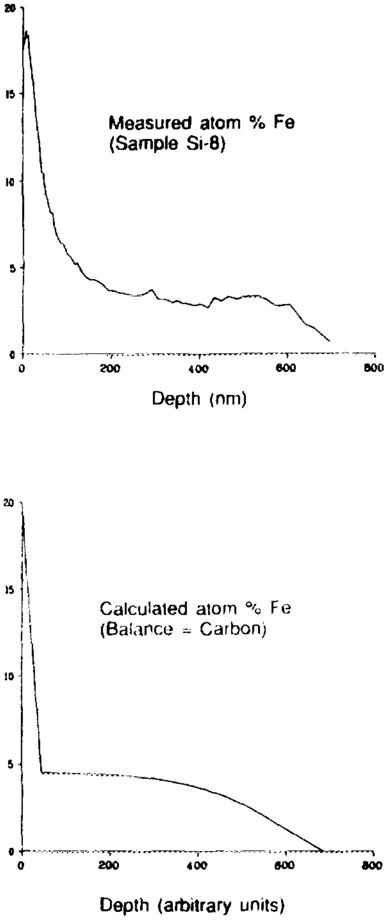
During the present tokamak upgrade period, experimental data acquired during the first tokamak operating phase (March 1987—December 1988) continues to be analyzed. Here are some recent results.

First wall deposits on long term samples.

Depth profiling of 'tokamakium' deposits on long-term tokamak wall samples has provided interesting data. In summary, thickness of deposits varies depending on location of the sample coupon in the tokamak, and the composition of any one deposit on a single sample coupon varies with depth. Only pure silicon samples collected deposits over long periods; stainless steel sample coupons collected no significant long term deposits.

Ten pure silicon coupons were exposed in Tokamak de Varennes for periods up to two years. All samples were exposed to glow discharge cleaning and a variety of tokamak operating modes including unstable discharges and low density discharges with strong X-ray production. Analysis of depth and composition of deposits on 10 pure silicon sample coupons by Auger Electron Spectroscopy (AES) indicates that:

- Silicon sample coupons retained deposits much more readily than comparably exposed stainless steel coupons, which were effectively cleaned during tokamak glow discharge cleaning.
- Material sputtered from tokamak components may not distribute itself evenly around the tokamak circumference; for example, there was considerably more molybdenum on coupons located near a molybdenum collimator tube than on other coupons around the circumference of the tokamak.
- Inconel guard limiters were a disproportionate source of metal contamination, contributing approximately 20% of metal atoms found in deposits, while the exposed surface of the guard limiters is less than 0.5% of the plasma chamber internal surface area.



Measured vs. calculated iron concentrations in tokamak wall deposit. Calculations performed with developmental sputter/re-deposition model.

- On samples unaffected by glow discharge cleaning, the metal concentration (atom %) at the surface of the deposit was significantly greater than in the bulk of the deposit. A sputtering-redeposition model which has the potential to explain this observation is being investigated. The inference is that metals tend not to become buried, but to remain at the surface of the deposited layer. *More Information: Prof. Roy Paynter, INRS-Énergie, (514) 468-7748.*

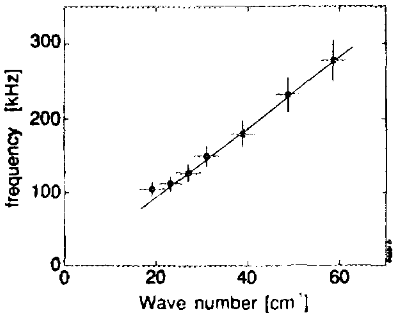
Plasma microturbulence measurements by CO_2 laser scattering.

Though it is not well understood, the phenomenon of plasma turbulence (collective movement of plasma electrons) is known to influence the energy confinement qualities of a tokamak plasma. Turbulence is invoked to explain anomalous losses of particles and energy in tokamaks. CCFM experiments with small-angle scattering of CO_2 laser radiation (10.6 micron wavelength) have yielded reliable data on turbulence wave propagation.

Results to date are encouraging; they indicate that drift waves, excited in the region of large plasma electron density gradients, are a significant contributor to turbulence in Tokamak de Varennes discharges with high plasma current and electron density.

Measurements with the recently commissioned CO_2 laser scattering diagnostic show that turbulence waves in the 1–3 millimetre wavelength range (wave number range 20–60 cm^{-1}) have a velocity of 300 metres/second and clearly exhibit linear dispersion. Linear dispersion means that wave frequency is linearly proportional to wave number k, where $k = 2\pi/\lambda$. The linear dispersion and the turbulence wave velocity are both consistent with theoretical predictions of drift wave excitation.

Work on turbulence measurement will continue in the next experimental phase. The CO_2 scattering diagnostic is being modified to allow measurements at longer turbulence wavelengths, in the 3–10 millimetre range. This entails installing telescopes in the optical measurement paths to permit measurements at smaller laser beam scattering angles, in the 0.06–0.20 degree range.



Turbulence wave dispersion characteristic - Tokamak de Varennes. Plasma current = 250 kA, central electron density = 5 x 10^{19} m^{-3}

The diagnostic also measures evolution of turbulence during any plasma shot, integrated along the chord of observation. This has proved useful in correlating observed changes in plasma parameters with changes in turbulence levels, during experiments such as limiter biasing or fast plasma current rampdown. *Further information: Alain Boileau, CCFM, (514) 652-8706.*

Plasma edge measurements.

A novel technique is being developed for determining electron density n_e and temperature T in the plasma edge regions. The technique depends on measurements of spontaneous radiation emitted by atoms sputtered from a surface placed in contact with the plasma. During the first experimental phase, measurements were made of visible radiation (445.3 nanometers wavelength) emitted by titanium atoms sputtered from a titanium carbide test limiter. At a given test limiter position, the decline of titanium radiation intensity with increasing distance from the limiter surface, due to titanium atom ionization, is a function of $[n_e/f(T)]$. At the same limiter position, thermocouple measurements of power deposition P on the limiter provide data on plasma density and temperature, according to $P = kn_eT^{1.5}$ (ref. 1). Data manipulation gives unique values for n_e and T near the test limiter surface. While it is as yet imperfect, the technique shows significant promise. In particular, measurements of radiation in front of the divertor plates, which are currently being installed, will allow a determination of n_e and T near the plate surface. For her part in this work, graduate student Deborah Poirier (INRS-Énergie) was awarded the Lumonics Prize and an award from the Canadian Nuclear Association. *Further information: Deborah Poirier (514) 468-7734 or Barry Stansfield (514) 652-7735.*

1. P.C. Stangeby, "Physics of Plasma-Wall Interactions in Controlled Fusion", Plenum Publishing, New York, 1986.

CFFTP

Annual Report Published

The 1988/89 Annual Report of the Canadian Fusion Fuels Technology Project is now available. Achievements, scientific and engineering work and the scope of international collaboration are described. The Report lists all CFFTP technical reports published since January 1988. Copies of the CFFTP 1988/89 Annual Report are available from: Sonja Morgan, Operations Coordinator, CFFTP (See Contact Data).

CFFTP now also publishes a technical newsletter called CFFTP Journal. It is intended for fusion workers in Canada and abroad, to keep them abreast of technical developments and initiatives at CFFTP. It is published three times per year and is free of charge. Contact Sonja Morgan, CFFTP.

Materials Research for Fusion Reactors

University of Toronto Institute for Aerospace Studies (UTIAS).

The UTIAS fusion materials program specializes in erosion behaviour and hydrogen retention studies on first wall materials—those materials in contact with or directly facing the fusion plasma inside a fusion reactor.

A three year UTIAS program, recently started, will study erosion and hydrogen isotope retention/re-emission with modified carbon materials, such as carbon doped with low atomic number (low Z) elements like boron and silicon. The UTIAS fusion group has also developed an impurity transport code called LIM which models erosion, including redeposition of eroded material and particle transport to and from the plasma. Program leaders are Prof. Anthony Haasz (materials experiments) and Prof. Peter Stangeby (impurity transport modelling). Fusion-related research at UTIAS started in the early 1970's.

Graphite is projected to have unacceptably high erosion rates as a lining for fusion reactors, especially if used for divertors or limiters which touch the fusion plasma. Erosion rates could be as much as one metre per year for graphite limiters or divertor plates in a next step machine such as ITER. Fabrication of materials with improved erosion resistance is considered essential to the exploitation of fusion power. Candidate materials include various composites, compounds and coatings based on beryllium, boron, carbon and silicon. UTIAS has chosen to study graphite and carbon composites doped with such elements.

One of the Institute's goals is to develop and test erosion-resistant first wall materials for the next step fusion reactors which may be committed in the next decade.

The Canadian Fusion Fuels Technology Project (CFFTP) and the ALCAN Ltd. *Kingston Research* Centre are research partners in the work. ALCAN will fabricate carbon/carbon composite specimens for testing, and investigate processes for bulk doping of such materials. Plasma exposure experiments take place in UTIAS laboratories. A recently commissioned tritium laboratory at UTIAS can expose specimens to tritium under fusion-relevant conditions.

As an outcome of the work, it is intended that a Canadian research consortium build a prototype plasma-facing component (divertor, limiter, or wall tile) and test it in Tokamak de Varennes or another facility.

Erosion Processes

Three main processes will affect erosion in fusion reactors. There is a characteristic temperature range where each one dominates:

- Physical Sputtering; up to 500 K
- Chemical Erosion; 500 K to 1200 K
- Radiation-enhanced sublimation; 1200 K to 2000 K

Sputtering is the dislodging of surface atoms through the impact of impinging particles. Chemical erosion involves the formation of volatile molecules which then escape. RES is a complex mechanism which is poorly understood as yet; it is a form of sublimation influenced by the type and flux rate of impinging particles. Synergistic erosion mechanisms—erosion under bombardment by more than one particle type—can increase erosion rates significantly, compared to single species impact. Synergistic erosion research is very relevant to fusion reactors, since fusion plasmas emit mixed particle fluxes in a broad energy range.

UTIAS Experimental Program

Work concentrates on fundamental *research into the processes* responsible for erosion and hydrogen/tritium mobility under fusion reactor conditions. Specimens are exposed to fusion-relevant vacuum, temperature and particle flux conditions. Synergistic erosion mechanisms are of special interest; previous studies at UTIAS have identified significant erosion enhancement under combined impact of hydrogen ions and neutral thermal hydrogen atoms.

Three key phenomena in plasma-materials interaction are being investigated with the doped carbon samples:

- Erosion processes (sputtering, chemical erosion, RES).
- Hydrogen isotope retention and re-emission during exposure to neutral and ionized hydrogen.
- Release of retained hydrogen by chemical reactions.

Controlled experiments are performed under ultra-high vacuum, with a wide variety of particle types and energies, at temperatures up to 2,000 K. Specimens can be bombarded with neutral and/or ionized atoms including hydrogen, deuterium, tritium, oxygen, carbon and helium, and with electrons, over a wide energy range.

Erosion studies. Modified graphite specimens will be exposed to controlled fluxes (10^{12}–10^{16} ions/cm^2/second) of mass-analyzed low energy (20 eV–10 keV) hydrogen and deuterium ions. Erosion rates will be measured by monitoring reaction products with a quadripole mass spectrometer. Preliminary studies on boron carbide (B_4C) indicated chemical erosion rates comparable to physical sputtering rates under expo-

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sure to hydrogen ions in the 300 eV–3 keV range. A dual beam accelerator is under construction, for synergistic erosion work. With this facility, the group will simultaneously bombard specimens with low energy hydrogen atoms and energetic impurity ions including carbon and oxygen. Synergism with low energy hydrogen atoms and thermalized helium ions will also be examined.

Hydrogen isotope retention and re-emission. Experiments will be performed with hydrogen, deuterium and tritium (H,D,T). Topics include:

- H,D,T retention as a function of ion flux, energy, fluence and specimen temperature.
- Release of H,D,T trapped in the specimen, under controlled atmospheric exposure.
- Release of retained H,D,T by chemical reactions with atoms or molecules of oxygen, nitrogen and other elements.

The latter two items are important to operational safety of fusion reactors.

Impurity transport modelling. This parallel study addresses behaviour of particles leaving a first wall surface, and their interactions with the plasma. Key topics are the probability of particles entering the core plasma, and the net erosion rate taking into account redeposition of eroded particles. The LIM code developed for this work uses as input the erosion data from the experiments mentioned above, and a definition of the fusion plasma edge conditions such as density, temperature, flow velocity and electric field parameters. The LIM code has been used at JET to evaluate plasma impurity levels and net erosion/deposition at limiter surfaces.

Fusion research at UTIAS is supported by CFFTP, NSERC and the Ontario Centre for Materials Research.

More information from: UTIAS Profs. Anthony Haasz or Peter Stangeby. CFFTP Paul Gierszewski (See Contact Data).

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.

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