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ITER

ITER Siting:

Economic Impact Study of Canadian Site for ITER

The economic impact of constructing an ITER-like reactor at a Canadian site has been assessed in a preliminary study, sponsored by the Canadian Fusion Fuels Technology Project (CFFTP). The study was intended to produce a first-look assessment of the economic benefits to Canada, in the hypothetical case that a fusion reactor similar to ITER were to be sited in Canada.

In 1992, a mixed committee of industry, CFFTP and the National Fusion Program began examining the feasibility and implications of using a Canadian site for construction of the ITER reactor, or a reactor like ITER. That is, a tritium-burning fusion reactor producing power in the range of 1,500 - 2,500 MW.

The economic impact study was performed by Wardrop Engineering, Inc. It concluded that there could be a large positive economic impact for Canada, assuming certain constraints. A sophisticated economic/technical model was assembled for the study.

It must be emphasized that the study examined hypothetical cases only. The assumptions made were deemed reasonable, but do not represent commitments by any parties. The study itself examined postulated siting scenarios, and the sensitivity of economic impacts to variations in parameters such as operational costs, and the effects on industry and the technology infrastructure in Canada.

The study assumed that any country selected to construct the reactor would most likely be expected to contribute a prepared site, as a balancing item for anticipated domestic economic benefits arising from the siting.

It was also assumed that Canada would contribute to the construction and operation costs, in proportion to Canada's involvement in ITER. Under the present terms, Canada is contributing 2.5% of the R&D costs of the currently ongoing ITER Engineering Design Activities. Canada contributes to ITER through the European Community. The costs of contributing tritium as fuel for an ITER-like reactor built in Canada were also examined.

As a reference site, the study chose one of the three CANDU nuclear power sites in the Province of Ontario. These sites are situated on the shores of the Great Lakes. Such a site would have adequate transportation access, adequate electrical power and cooling water supplies, and would also meet seismic requirements.

Further information from Don Dautovich, Manager - CFFTP, or from Bill Holtslander, NFP (See Contact Data).

Harvey Skarsgard

Canadian Fusion Pioneer Retires

Professor Harvey Skarsgard, a pioneer of plasma physics and fusion research in Canada, retired in July from his position as Director of the Plasma Physics Laboratory at University of Saskatchewan. He will remain associated with the Physics Department as Professor Emeritus.

The vigour and focus of today's fusion programs in Canada owe a great deal to Dr. Skarsgard's drive and enthusiasm for fusion and plasma physics over the last forty years. Since the 1960s, he was a nationally recognized advocate of fusion. He was a senior adviser to the pivotal **Fusion Canada** Study of 1974-75, which determined the direction of today's National Fusion Program and resulted in the construction of the TdeV tokamak at CCFM, and in Canada's emphasis on fusion fuels technologies by CFFTP. Canada's first tokamak was built at University of Saskatchewan in 1983.

Dr. Skarsgard received his Master's degree in Physics from Saskatchewan, and his Ph.D. from McGill University in 1955. Like other pioneers in plasma physics, Prof. Skarsgard taught himself the subject for the most part, since few institutions

continued inside

CCFM/TdeV Update

Biased divertor experiments with auxiliary LH heating

With the TdeV tokamak, CCFM continues its work on biased divertor research, now done with the addition of 3.7 GHz radiofrequency (RF) lower hybrid current drive and auxiliary heating.

It has been established that electrically biased plasma operation with pumped divertors is compatible on TdeV with RF power injection. Biased divertor operation is improved by the RF auxiliary heating.

Routine operation of TdeV is with biased plasma, pumped divertor operation, and with RF current drive/plasma heating at RF power levels typically in the range 400 - 800 kW. TdeV is now operated almost exclusively in single null plasma geometry, so that only one divertor is in use, and is fuelled with deuterium gas. Plasma chamber wall conditioning by boronization with diborane gas is also routine.

Since May, the upper divertor geometry was modified with new divertor plates and electrical configuration, giving better control of radial electric field in the plasma's edge, or *scrape off layer.*

Compact toroid fuelling results have been good. It is now established that high velocity compact plasma toroids injected into TdeV have penetrated the central plasma to increase central plasma density.

Some operating parameters have been extended on TdeV:

- A new high plasma density of 7.9 x 10^{19} m^{-3} has been achieved, because of improved plasma chamber wall conditioning by boronization. This is now done with the automated boronization system, installed some months ago, using deuterated diborane gas glow discharges.
- Plasma pulse length has been increased to a TdeV record of 3.8 seconds by driving some of the plasma current (210 kA nominal) with the 3.7 GHz lower hybrid RF system. The RF system typically operates for about 2.5 seconds during a 3.8 second pulse, with a 3.5 second "flat top" plasma current plateau.
- Maximum RF lower hybrid power injected into the plasma has reached 870 kW, albeit at fairly low plasma density (~2 x 10^{19} m^{-3}).
- Helium pumping performance, via the biased divertors, has been improved somewhat. The ratio of helium evacuation time to plasma energy confinement time provides a figure of merit indicating the effective helium removal rate from the plasma. The lower this ratio, the better the helium removal efficacy will be. With the new divertor, under negative biasing, a ratio of about 10 has been achieved, compared with a ratio of about 20 achieved last year. This helium extraction performance is in the range that fusion reactors are expected to need.

Experiments to characterize the coupling and deposition of lower hybrid RF energy into the plasma are consuming much effort. The RF multijunction antenna is electrically isolated to 'float' at a potential dictated by TdeV operating conditions, and the antenna can be moved radially to adjust the distance between the antenna mouth and the plasma separatrix (the outermost closed magnetic flux contour). The size of the antenna-plasma gap is found to have

Harvey Skarsgard *continued*

taught plasma physics in the 1950s and early 1960s. He invented the plasma betatron, a toroidal device geometrically and magnetically similar to a tokamak, but intended to produce high flux, high energy electron beams. It was during the betatron work that he encountered - unexpectedly - the phenomenon now known as turbulent plasma heating. He explored turbulent heating assiduously, and is widely known for his valuable contributions to plasma physics in that area.

One of his greater achievements in plasma physics was to attract and direct a number of very capable researchers and post-doctoral fellows, and to train many post-graduate students. He established the Plasma Physics Laboratory at University of Saskatchewan. On Dr. Skarsgard's retirement, Prof. Akira Hirose has been appointed Director of that Laboratory.

Well-wishers may reach Dr. Skarsgard at University of Saskatchewan Physics Department: (306) 966-6436, fax (306) 966-6400.

INTERNATIONAL

Europe's Fusion Funding 1994-1998

Euratom's Proposals for Fusion

In autumn this year, the Council of the European Union (EU) will decide on the next four-year fusion R&D program for the European Atomic Energy Community (Euratom). Euratom coordinates the whole fusion R&D program of the European Community.

The fusion programs of Canada and of Euratom have been linked since 1986 by bilateral cooperation agreements, and Canada contributes to the International Thermonuclear Experimental Reactor through Europe. In view of the these Canada-Europe associations in fusion R&D, we present for the information of our readers an outline of Euratom's proposals for its program funding and activities for the next four years. The information was released earlier this year by the European Commission and published in full in the *Official Journal of the European Communities.*

The new Euratom budget for fusion activities is estimated at Ecu 840 million, to be spent over the four-year period January 1, 1995 to December 31, 1998. One Ecu (European Currency Unit) is equivalent, in August 1994, to about 1.6 Canadian Dollars, or 1.22 US dollars. Because the bulk of this money is core funding, which supplements fusion spending in individual European countries, the actual total four-year level of fusion spending will be much greater. Budget proposals are drafted by the European Commission (EC), on behalf of Euratom. The funding can be reviewed in 1996.

Euratom-funded fusion work concentrates on magnetic fusion in toroidal geometry. Work on other approaches, including inertial confinement, is at the level of 'keep-in-touch' activities. Europe's priority fusion objective, from 1994 to 1998, is to establish the engineering design of the Next Step reactor. This is seen as being done via Europe's participation in the Engineering Design Activities (EDA) of the International Thermonuclear Experimental Reactor (ITER).

Canada and Euratom have had bilateral fusion collaboration agreements since 1986. Currently, Canada and the EC have negotiated renewal, on an expanded basis, of the most recent Canada-Euratom fusion bilateral agreement, and the renewed agreement is awaiting ratification. Under these bilateral fusion agreements, Canadian companies and R&D sites are eligible to participate, where appropriate, in EU-funded fusion R&D programs.

The European Union mechanism for providing common fusion R&D funds is via consecutive four-year R&D programs, under an overall EC program known as the 'Framework Program in the field of Research and Technological Development'. The framework program sets out the long term objectives in the different domains of activities (which are then further specified in the so-called 'specific' programs), and sets out the level of activity in each domain. In effect, the framework program is a combination of policy and strategy. The global budget of the EU 1994-1998 Framework Program for nuclear and non-nuclear R&D is 12.3 billion Ecu, dispensed primarily on a cost-shared basis.

Funding estimates are based on Euratom's analysis of its own projected fusion programs and on Europe's participation in international fusion including the ITER EDA.

Two 'Specific' Programs Covering EU Fusion Activities

The estimated Ecu 840 million fusion budget is supplied from two separate 'specific' programs.

The largest of these two programs provides the main fusion funding, estimated at Ecu 794 million. This can be considered as core or 'base' funding; EC funds for a specific project or activity are generally complemented by co-funding from the country or site hosting that project or activity. Monies from this funding program are allocated among identified R&D programs at sites throughout the 12 countries of the EU, and in Switzerland and Sweden which are Euratom associate countries. Because of the co-funding, the Ecu 794 million common funding program anchors a total fusion spending in Europe that might be more than double that amount.

Proposed allocation of the Ecu 794 million is as follows:

Next Step Activities (chiefly ITER EDA)	40 - 50 %
Joint European Torus (JET Joint Undertaking)	22 - 32 %
Concept Improvements	22 - 32 %
Long Term Technology	5 - 9 %
	100 % (= Ecu 794 million)

Economic and safety issues will play an essential role in the progress of the whole EU fusion program. In JET, they are an integral part of the site's efforts; in the three other areas above, the issues will receive about 10% of the budget.

The second of the two 'specific'

ITER

New Director for ITER Joint Central Team

Dr. Paul-Henri Rebut has stepped down as Director of the Joint Central Team (JCT) of the International Thermonuclear Experimental Reactor (ITER). Dr. Robert Aymar, of France's Commissariat à l'Énergie Atomique (CEA), was appointed by the ITER Council at its July 27-28 meeting to replace Dr. Rebut as Director of the ITER JCT. Dr. Aymar's appointment was made effective from the meeting date.

On behalf of Canadian fusion workers, the National Fusion Program wishes to express its appreciation of Dr. Rebut's dedication, leadership and contributions as ITER JCT Director.

Before being appointed Director of the JCT, Dr. Aymar was Directeur des Sciences de la Matière for CEA, and before that was head of the Tore Supra Project, a large superconducting-magnet tokamak in France. Like Dr. Rebut before him, Dr. Aymar faces the demanding task of coordinating the research and design work of three JCT sites and four Home Teams, spread across three continents, towards producing a coherent and practical ITER reactor design. The National Fusion Program extends its best wishes to Dr. Aymar and his team, and looks forward to continuing Canada's involvement in the ITER EDA.

ITER

Safety Expert for ITER JCT

San Diego

Dr. Charles Gordon, a Canadian senior nuclear safety expert, is joining the Joint Central Team (JCT) of the ITER Engineering Design Activities (EDA). He will begin work in safety and licensing activities at the JCT's San Diego Joint Work Site in October, working in the Nuclear Integration Division under Dr. Genn Saji.

Dr. Gordon is a Supervising Design Engineer with Ontario Hydro in the reactor safety department in Toronto. He has in the past been attached at JET to perform fusion safety studies and reviews. His San Diego attachment is funded by the Canadian Fusion Fuels Technology Project.

NATIONAL FUSION PROGRAM

Exchange of Roles in NFP Office

Dr. Bill Holtslander
Dr. Gil Phillips

In the office of the National Fusion Program (NFP), Bill Holtslander and Gil Phillips have exchanged jobs effective July 1, 1994.

Bill Holtslander has been appointed as NFP's Manager-Fusion Fuels. In this position, he will provide liaison between NFP and the Canadian Fusion Fuels Technology Project (CFFTP). This role includes working with CFFTP to continue developing and strengthening Canada's R&D in fuelling and tritium handling technologies, and remote handling. Dr. Holtslander has considerable experience of working in tritium technology with AECL and was previously Manager-International Program for NFP.

Gil Phillips is now appointed Manager-International Program for NFP. In this position, he is responsible for NFP liaison in international matters, including adoption and management of bilateral collaboration agreements with other fusion programs, including those of Europe, the USA and Japan. Before joining NFP in 1987 as Manager-Fusion Fuels, Dr. Phillips was a reactor physicist.

Phillips and Holtslander will maintain their present responsibilities concerning Canada's involvement in the international fusion collaboration agreements of the International Energy Agency (IEA). Dr. Phillips will continue to represent Canada for the IEA *Fusion Materials* agreement. Dr. Holtslander will continue to represent Canada for the IEA *Environmental Safety and Economics* agreement and for the *Nuclear Technology of Fusion Reactors* agreement. In addition, Dr. Phillips will continue as NFP representative on the CFFTP Industrial Advisory Committee. Dr. Charles Daughney of NFP continues to represent Canada for the IEA *TEXTOR* agreement.

a significant effect on RF coupling and on RF energy deposition in the plasma. Two special diagnostics are now in use to observe the high speed electrons generated by RF injection and current drive. An electron cyclotron transmission diagnostic (a form of microwave absorption spectrometer) is operational - it was developed by University of Maryland in conjunction with CCFM. A new hard X ray spectrometer observes the bremsstrahlung radiation resulting from deceleration of high speed electrons in collision with plasma ions.

Compact Toroid Fuelling

CCFM researchers are now satisfied that centre fuelling of the plasma on TdeV, without disruptions, has been achieved by injection of high speed compact toroid (CT) plasma spheromaks. A Canadian-built compact toroid fueller (CTF) was used to launch CTs at speeds up to 220 km/s, penetrating to the TdeV central plasma, with the TdeV toroidal magnetic field (B_T) between 0.73 tesla and 1 tesla. It is believed that this is the first time a medium-sized tokamak has been fuelled without tokamak plasma disruption using a CTF. For these experiments, TdeV was operated in double-null plasma configuration with plasma densities between 1 and 2 x 10^{19} m^{-3}.

Typical CT parameters measured in the CTF, before injection into TdeV, are: average velocity 120 - 220 km/s, density of 2 - 7 x 10^{20} m^{-3}, mass of 10 - 30 micrograms, and a CT poloidal magnetic field of 0.4 - 0.8 tesla.

In the tests with B_T at 1 tesla, the CT injection increased TdeV particle inventory by more than 30%. Central density peaked less than 0.5 milliseconds after particle injection, and the higher plasma density lasted a few milliseconds. By contrast, an ordinary fuelling pulse by gas puffing at the plasma edge causes central plasma density to peak after perhaps 12 milliseconds or more.

At B_T = 1.5 tesla, only partial penetration of the TdeV plasma by the CT was achieved. To fully penetrate the plasma at $B_T \geq 1.5$ tesla, higher CT injection velocities would be required, beyond the capability of the CTF in its present form.

It is recognized that these are early results, but CCFM staff believe that they are sufficiently encouraging that further exploration of CT fuelling technology for tokamaks is warranted, especially in view of the fact that no completely satisfactory technology is yet available for fuelling future tokamak fusion reactors.

New Divertor Configuration

The upper divertor design was modified to install a new divertor plate, made of carbon fibre composites. This new plate is electrically grounded. With this configuration, it is possible to control the radial electric field in the plasma scrape off layer (SOL) entirely from within the divertor. It is now well established that the SOL radial electric field has a vital role in determining SOL behaviour, and thereby greatly influences divertor particle collection, the tokamak power deposition profile and numerous other plasma behaviour aspects. The new divertor design was also aimed at exploring the beneficial effects of positive plasma biasing. A new divertor outer neutralizer plate, instrumented with more flush-mounted Langmuir probes, was also installed.

The new configuration has shown good performance with negative plasma biasing, contributing to improved particle retention (as evidenced by more easily controlled divertor pressures) and the observed improvement in helium removal from the main plasma. Easily controlled **ExB** particle flow towards the active divertor is observed with negative biasing. With positive biasing, however, the new divertor does not function as well as model predictions indicate. Investigations continue.

Further information: TdeV Research - Brian Gregory (514) 652-8729: TdeV Operations - Réal Décoste (514) 652-8715: CT Fuelling - Roger Raman (514) 652-8859. Or fax CCFM (514) 652-8625.

EDUCATION

Fusion Education Booklet

Readers are reminded that the illustrated colour brochure *"Fusion: Energy for the Future"* is available, free of charge, for teaching and education purposes. English and French editions are available.

The 32 page booklet, in 8½" x 11" format, explains the fusion process and fusion reactor concepts at a level suitable for high school students and the general public. Environmental, fuel supply and waste management aspects are also addressed. In its second half, the booklet gives overviews of Canada's fusion program and of the ITER collaboration. The booklet was produced as a public service by the National Fusion Program.

Quantities up to 50 copies (either language or both) are available by contacting the *FusionCanada* editorial office operated by Macphee Technical Corp. *(see Contact Data).*

programs is intended for wholly supporting the European Commission's Joint Research Centre (JRC). The JRC is a particular group of sites dedicated mainly to nuclear safety and safeguards, and completely funded by common EC funds. The total JRC funding estimate for four years is Ecu 300 million, of which Ecu 46 million is allocated for fusion. The Ecu 46 million will mostly be spent for commissioning and operating Europe's **Ethel** Tritium Laboratory located at JRC Ispra in Italy.

After several steps, including the opinion of the European Parliament, the specific programs are decided upon by the Council of the EU. The decision is expected before the end of 1994. The European Commission's DG XII (on behalf of Euratom) administers the funds.

Europe's long term fusion objective is the joint creation of safe, environmentally sound prototype reactors which should result in construction of economically viable power stations. Particular attention will be given to the requirements of power utilities.

NEW ADDRESS

National Fusion Program Office

Change of Mailing Address

In July, the program office of the National Fusion Program was moved to another building. Please note the **new mailing address** given below, and update your files.

There is **no change in Fax and telephone numbers.**

New Mailing Address:

National Fusion Program
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National Fusion Program

Director, *Dr. David P. Jackson*

The National Fusion Program (NFP) co-ordinates 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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