INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR

INIS-XA--087

XA9848910 - 9/3

ITER EDA NEWSLETTER

VOL.7, NO. 6 JUNE 1998

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, AUSTRIA

ISSN 1024-5642

XA9848911

ITER REPRESENTATION AT THE ELEVENTH PACIFIC BASIN NUCLEAR CONFERENCE

by Dr. G. Saji, Head of Safety, Environment and Health Division, ITER Joint Central Team

Approximately 700 delegates from 29 countries met in Banff, Canada from May 3-7, 1998 for the 11th Pacific Basin Nuclear Conference, including delegates and a technical display representing ITER. The location and the timing of the conferences were particularly fitting in view of Canadian and Japanese interest in hosting ITER and to demonstrate to a wider nuclear community that the ITER Project has established a remarkable achievement during EDA and is ready to proceed to construction at a site still to be determined.

The Pacific Basin Nuclear Conferences were initiated originally as a regional co-operative organ to advance peaceful uses of nuclear energy in the Pacific Basin region. The first meeting was held in 1976 and they have been held every two years. The conferences have played an important role in providing a forum to share information relating to both research and development and to the implementation of nuclear technology in the Pacific Basin. This year's conference was sponsored by the Pacific Nuclear Council (which includes nuclear societies from the Australia, Canada, China, Indonesia, Japan, Korea, Latin America, Mexico and the United States) the Canadian Nuclear Association and the Canadian Nuclear Society. Nuclear Society of Russia is also among the observer societies of the Pacific Nuclear Council.

The theme of the conference this year was "international co-operation in the Pacific rim for the 21st century" reflecting both the historical objectives of the PBNC meetings and to focus on ways in which international cooperation can assist in overcoming the challenges to further realization of the many benefits of nuclear technology, particularly in the countries of the Pacific Rim.

ITER Booth at the Conference

ITER Technical Presentations

Dr. Y. Shimomura participated in a Plenary Session on Nuclear Technology and Fusion and provided a comprehensive overview of the ITER project and the design. This talk (reinforced by the presentations in the dedicated parallel session on ITER) noted (1) the high degree of international co-operation evident in ITER as exemplified by the magnet R&D projects; (2) that the ITER design as well as being a comprehensive and integrated design is well supported and demonstrated by key R&D project results, and (3) that the design is sufficiently well-defined and analyzed, and strengthened by R&D to support a decision to proceed to construction.

A parallel session dedicated to ITER was organized on International Co-operation in Fusion - ITER and five presentations made. Their abstracts are reproduced below:

S. Matsuda et al, "*Progress of ITER R&D in the Japanese Home Team*". This paper reports on the progress of ITER R&D in the Japanese Home Team. In close collaboration with more than 30 top level industries and many universities, various R&D tasks assigned to the Japanese Home Team have been conducted. In particular, reactor structures such as superconducting coils and in-vessel components such as blanket and divertor, out-of-vessel components such as heating and current drive systems, remote maintenance technology, and seismic isolation systems have shown significant progress.

C. Baker et al, "*Highlights of ITER R&D in the USA*". The U.S. Home Team, in close collaboration with the ITER Joint Central Team and other Home Teams, performs certain technology R&D tasks for the ITER Project. This paper provides an overview and update of the current status of such tasks. The U.S. Home Team devotes most of its effort to the Central Solenoid Model Coil and the Divertor Cassette projects. Additional efforts are devoted to safety issues, limiter components, vacuum vessel welding, ion cyclotron heating components, fueling and tritium components, and diagnostics.

C. Gordon et al, "*International Co-operation in the Safety and Environmental Assessment for the ITER Engineering Design Activities*". The ITER EDA include design and assessment activities to ensure the safety and environmental attractiveness of ITER and demonstrate that it can be sited in any of the ITER Parties with a minimum of site-specific redesign. The high level of interaction, co-operation and collaboration between the Joint Central Team and the Home Teams, and between the safety team and designers, and the spirit of consensus that has guided them have resulted in a safe design for ITER and a safety design and assessment that can meet the needs of the potential host countries.

C. Ahlfeld et al, "*ITER Site Plan and Tokamak Buildings*". This paper describes the ITER Site Plan and Tokamak Buildings design completed during the EDA. The Site Plan evolved from the development of the ITER Site Requirements and Design Assumptions which is one of the EDA deliverables. Additional features of the Site Plan were the result of building designs and the routing of services for the operation of the tokamak and its support systems. The focal point of the Site Plan is a cluster of buildings referred to as the Tokamak Buildings. At the centre of this cluster is a deeply embedded cylindrical pit that contains the tokamak in a cryostat.

D. Murdoch et al, "*Canadian Contribution to the European Union Home Team Program for ITER*". Canadian participation in R&D and design tasks for the ITER project is predominantly in the Fuel Cycle, Remote Handling and Safety fields. These tasks are carried out in Canada by Ontario Hydro, research institutes, industry and universities. In addition, Canada provides the services of a number of specialist engineers and scientists in key positions in the ITER JCT in the European Home Team. The Canadian contribution, which is co-ordinated now by ITER Canada, forms an integral part of the European Home Team program.

ITER Booth

In addition to the above sessions, the ITER presence at the Pacific Basin Nuclear Conference was significantly enhanced by an ITER Booth at the Technical Exhibit held during the Conference. The exhibit included on-going videos explaining fusion in general and featuring R&D projects for ITER; many large-scale photographs of ITER R&D contributed from all the Home Teams, and a 1/30 scale model of the ITER tokamak contributed by the Japanese Home Team. The engineering model, a large (about 1.5 m x 2.4 m) photo of the full scale Vacuum Vessel Sector Model, and large photos of model coils impressed audiences in particular, by indicating that fusion development has come to this stage. The audiences included many influential people in the wider nuclear communities in the Pacific rim countries.

The Exhibit was organized and staffed by G. Saji and E. Golubchikova, supported by M. Araki, and S. Kosaka and the presenters noted above. Around 200 visitors signed the guest logbook and received packages of brochures on fusion and ITER. These packages included the following brochures produced and donated by various organizations:

International Thermonuclear Experimental Reactor, by ITER Joint Central Team
The Pervasive Plasma State, by the American Nuclear Society
Fusion Science - Harnessing the Energy of the Stars, by US DOE
Investment of an Energy Source for Tomorrow- FUSION Yields Important Benefits Today, by US DOE
Eight Reasons to Support Fusion Energy, by PPPL
DIII-D National Fusion Facility and GA Fusion Research, by DIII-D
Nuclear Fusion - Energy for Centuries to Come, by JET
Nuclear Fusion - Status and Perspectives, by IPP
Naka Fusion Research Establishment, by JAERI
National Institute for Fusion Science - The LHD Project, by NISC

The Exhibit and attendance was a useful way to inform a broader audience about the benefits of fusion and status of ITER. It should be noted that the 12th Annual Pacific Basin Nuclear Conference, to be held in Seoul, Korea in 2000, already includes nuclear fusion as one of its topic areas.

With successful completion of the ITER EDA and in the post-Kyoto world, fusion development has a unique opportunity to position itself for a challenging but rewarding phase. Success can only by achieved by mobilizing widespread support of the nuclear industry and of the general public for fusion as an environmentally attractive and sustainable source of energy. The Conference provided an opportunity to reach a wider audience. The strong interest expressed in ITER by a broad range of Conference participants demonstrated the potential to build such support.

SUMMARY OF DISCUSSION POINTS AND FURTHER DELIBERATIONS IN THE SPECIAL COMMITTEE ON THE ITER PROJECT IN THE ATOMIC ENERGY COMMISSION (unofficial translation)

by H. Nakamura, Director for Fusion Energy, Atomic Energy Bureau, Science and Technology Agency, Government of Japan

The Special Committee on the ITER Project was established in December 1996 as a forum for a broad investigation of how to deal with various aspects of the ITER Project, such as its role in the international community or its social and economic implications, assuming that the Engineering Design Activities (EDA) of the International Thermonuclear Experimental Reactor (ITER) would be completed by July 1998 and the project would proceed to the construction phase.

Meanwhile, the international discussion among the four ITER Parties (EU, Russia, US and Japan) has been progressing in a direction to extend the EDA for three other years; furthermore, the Government of Japan has decided to suspend new megaprojects in science and technology, such as inviting ITER to Japan, during the remaining years of this century because of an intensive fiscal structural reform intended. Under these circumstances, the decision on the Japanese stance on proceeding to the ITER construction phase has been postponed.

However, considering that the EDA would reach the end of an epoch in July 1998, it is necessary to summarize the points of discussion made so far and to specify the direction to further discussions and a way to come the final conclusions of the Committee. Furthermore, the final conclusions will be made at an appropriate time in the future, depending on the progress of the EDA.

Outline of "Discussion points and further deliberations in the Special Committee on the ITER Project"

Global environment problem and energy problem

The energy problem, as well as the global environment problem, are global issues that cannot be overcome by symptomatic policies or measures only, nor can they immediately be solved by the development of new technologies. Therefore, a new cooperation is necessary and should be initiated as soon as possible in order to share the understanding of these issues and to develop and utilize effective means through global collaboration.

Promotion of the fusion energy development

Fusion energy should be discussed in the context of various energy resources. Considering the uncertainty of various other energy resources in the future and the advantages and technological feasibility of fusion energy, it is one of the promising options. Additionally, in view of the responsibility the present generation holds for the next generations, fusion energy development is of utmost importance.

It is also important to clarify the methods of handling the safety of fusion and the relevant development issues in the future, on the basis of excellent characteristics of the fusion energy.

ITER Project

The Committee confirmed that it is of great importance to Japan to host ITER for the following reasons. Japan should:

1) play a leading role in the international community not by simply providing economical means but also by creating knowledge and intelligence and providing technical solutions to global issues.;
2) contribute to the international community by scientific and technical potential in the areas of research, education and industrial technology;
3) expose its public understanding and consciousness such as thinking on the future of humanity from the viewpoint of morals of the Japanese society in both the international and the domestic areas. In addition, Japan should not lose the international trust which it has by its history of promoting the peaceful use of atomic energy and by its effort to spread, publish and support advanced technologies and science in the areas of manufacturing technology, etc.;
4) invest into fusion energy research and development for the sake of humanity's existence and welfare and to assure freedom of selecting future energy sources the investment should be regarded as a sort of insurance fee.

Although the investment can be considered as an inevitable insurance, the resources required for the project are estimated to approach one trillion yen in total in the Interim Design Report of EDA and hence are a major concern; it is thus important to maximize the positive outcome and to minimize the expense by balancing technical objectives, technical margin and cost.

Conclusion and further considerations

Even though it was recognized that hosting ITER is of great significance, the following studies are required for the final decision. The results of existing studies and/or new investigations, covering a broad range of options of related researchers, etc., with sufficient budget if necessary, are taken into consideration.

- Study of long term energy demand and supply;
- Feasibility study of alternative energy sources;
- Examination of technical feasibility of fusion energy;
- Investigation of future programs to support the project including supporting research studies, education and training of personnel;
- Study aiming at creating a philosophy of distributing the resources to various projects;
- Research on establishment of fundamental guidelines on responsibility sharing in international collaboration.

Additionally, the Committee will simultaneously discuss items such as:

- Comparison of siting ITER in Japan or abroad from various points of view such as the effect on technological innovations, and spin-off effects of enhancing economy;
- Fundamental criteria such as the responsibility and the financial allocation of the host country, including the operation phase;
- Issues to be prepared in Japan for conducting the ITER project such as organization and personnel assignment.

According to the progress made with above mentioned studies, the Committee will again discuss these items, summarize the results in a report and make a recommendation for the decision on the Japanese attitude as a final conclusion of the ITER project.

Future plans

Specialized investigations on the above mentioned items will be made during a period of about one year.

Depending on the progress in studying these issues, international discussion and the progress of EDA, the Committee will resume its activities in summer 1999 and conduct its discussions aiming to reach a final conclusion before summer 2000.

ITER RADIO FREQUENCY SYSTEMS

by Dr. G. Bosia, ITER Joint Central Team, Garching Joint Work Site

In ITER, auxiliary heating and current drive functions are likely to be shared among at least two of several different methods. A (negative ion) Neutral Beam Injection system and three Radio Frequency Heating and Current Drive (RF H&CD) systems: Electron Cyclotron (EC), Ion Cyclotron (IC) and Lower Hybrid (LH) Systems, are being developed during the Engineering Design Activities (EDA).

ITER RF systems offer a range of complementary services satisfying all ITER operational requirements. They can be used i) to access the H-mode confinement in D-T plasmas and to subsequently increase the plasma temperature to ignition values; ii) to supplement alpha heating in finite-Q driven burn scenarios; iii) to assist plasma start-up and shut-down; iv) to maintain sufficient plasma rotation to avoid locked modes and to stabilize resistive instabilities. The above functions (to be applied to plasmas within the density range $n_{e0} \sim (0.3–1.5)\times10^{20} m^{-3}$ and the temperature range 3–20 keV) may require a total auxiliary power of at least 100 MW. In addition, RF heating systems have several supplemental roles in the optimization of ITER operation, ranging from wall conditioning to plasma-initiation assist.

On- and off-axis current drive capabilities are required for extending burn, for local control of the plasma current profile, for stabilization of resistive MHD instabilities and ultimately, for steady state operation. According to present modelling, non-inductive currents of few MA need to be generated and controlled on- and off-axis, in plasmas with densities in the range of $n_{e0} = (0.6 - 1.5) \times 10^{20} m^{-3}$, and plasma current $I_p = 12 - 21$ MA.

Plasma heating and current drive functions need to be co-ordinated and controllable: multiple functions must be provided under closed loop control, in order to maintain a quasi-stationary burning plasma.

DESIGN

Five ITER equatorial ports may be allocated to the RF H&CD systems, and each system is designed to provide 50 MW of output powers even if the actually implemented power will be smaller. The system designs are now converging to a modular approach, which favours standardization and interchangeability. The level of standardization is being further increased as the design progresses and common mechanical components, structures and auxiliaries are being designed for the three systems.

In all systems, the launcher design incorporates a monolithic port plug assembly (Fig.1) with ceramic windows located at the main flange of the vacuum vessel port, to provide the primary containment boundary, and similar mechanical interfaces with the vacuum vessel. All port plugs are composed of nuclear shielding and power transmission components together with the mechanical assemblies needed to support these structures. All plugs feature an all-metal construction, do not extend ITER vacuum boundaries, fit within a standard remote handling transport cask and are designed to be assembled and disassembled in the hot-cell.

Electron Cyclotron

Electron Cyclotron (EC) wave absorption and propagation lead directly to electron heating and on- and off-axis current drive. The EC wave, launched in vacuum, propagates into the plasma without attenuation or interaction with the plasma edge and is absorbed by the electron population at the resonant layer. Consequently, the launching structure does not have to be close to the plasma.

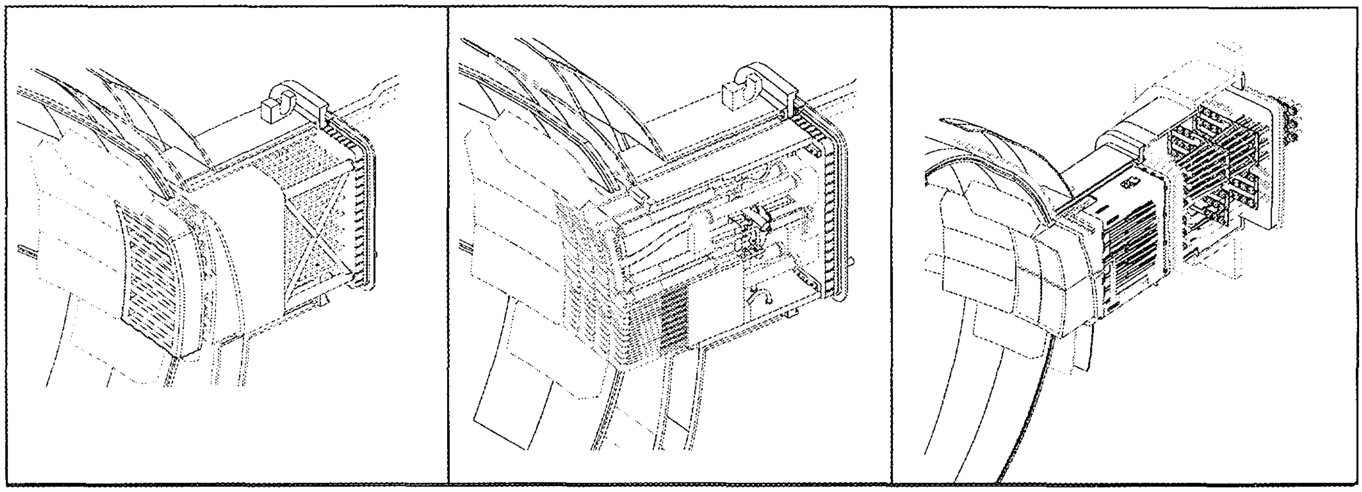

Fig 1. Isometric view of the RF launchers seen from the plasma :
a) EC Launcher; b) IC Launcher, c) LH Launcher

The radial control of the location of the power deposition is obtained through oblique launch of the wave in the toroidal direction. Extensive modelling has shown that the launch of a single frequency (170 GHz), elliptically polarized, ordinary mode wave from the low-field-side is sufficient for both heating and current drive, over a wide range of fields (4.0 - 5.7 T), provided that a modest steering capability is incorporated in the launcher design.

Two equatorial ports are used to inject 50 MW of EC power for both heating and current drive. The same two ports are also used for the EC start-up and wall conditioning system with one 4 MW system installed per port. The launch configuration is consistent with the requirements for start-up and wall conditioning although in this case, frequencies in the range 90-130 GHz are used and steerable injection is not strictly needed. An upgrade to a total of ~100 MW of injected power is possible without increasing the number of ports.

Power is injected into the torus through 7 slots in the shield-blanket by means of steerable mirrors, located behind the shield-blanket. Each row of 8 mirrors is actuated individually. Wave guides feeding the mirrors are offset relative to the slots in order to reduce direct neutron streaming which is further reduced by a "dog-leg" introduced in the wave guide run and sandwiched between segmented blocks of shielding to form a shielded labyrinth.

Corrugated circular wave guides are used for power transmission. A careful design of the transmission system is needed to accommodate wave guide distortions, (e.g. due to the relative radial motion between the vacuum vessel and the cryostat), which can cause "mode conversion" and thus enhanced power dissipation. The calculations performed have been verified by experiment on a scaled wave guide run. The net measured mode conversion in these tests is less than 2%.

Ion Cyclotron
Ion Cyclotron Frequency is most suited for bulk ion heating and central current drive. Plasma heating is performed using well demonstrated heating schemes: the W_{He3} minority heating scheme for non-tritium plasmas and the $2W_T$ scheme for D-T plasmas. Both scenarios use the same frequency (57 MHz at full toroidal field). The system is however designed for a frequency range (40-70 MHz), which allows a substantial flexibility with regard to B_T changes and includes the W_D minority scheme.

Fast Wave Current Drive (FWCD) is simply obtained by asymmetrically phasing the IC array, without in-vessel hardware changes. Current drive projections for on-axis current drive are also based on a well established experimental database, with current drive efficiencies up to 0.04×10^{20}A/Wm^2 and a linear dependence with T_{e0}, in very good agreement with theory. In the frequency window selected for FWCD in ITER (f ~ 62 MHz), the electron absorption is in competition with $2W_T$ (on the high field side) or with $2W_D$ (on the low field side) ion resonances and the CD efficiency is optimized by properly locating the position of the two resonances out of the wave path. The extrapolation of current drive efficiency values to ITER leads to h=(0.15-0.25)x10^{20}A/Wm^2, with current profile peaked on-axis.

The system uses four equatorial ports for coupling 50 MW. Each array consists of eight current straps fed by one coaxial transmission line and tuned at the two ends by a pair of pre-tuners. The feeder is connected not far from the centre of symmetry of the strap, at a point where the capacitive admittance of the long section is compensated by the inductive admittance of the short one. A resonant l/2 double loop antenna results, whose electrical length can be adjusted for different frequencies. The (resistive) input impedance is matched to the feeder characteristic impedance. A nominal power of 2MW/strap (or a total of 64 MW) is available. The maximum operating voltage depends on plasma coupling. Present estimates show that a total of 50 MW can be delivered to the plasma at an operating voltage < 42 kV.

The Main Transmission Line is a conventional rigid coaxial line of 30 W characteristic impedance, water cooled and pressurized at 300 kPa pressure, with dry air used as dielectric gas and operated at relatively low voltage (< 20 kV peak).

Lower Hybrid

The Lower Hybrid (LH) wave system is proposed for: i) extension of the pulse length in the commissioning phase of hydrogen discharges, ii) stabilization of sawteeth in the standard ignition case, iii) steady-state operation and control in advanced scenarios, iv) current profile control during ramp-up and shut down.

LH waves are known as the best current drive system in present experiments and have the potential to be an important element for the ITER current profile control. Current drive efficiency is already high at low temperature and values exceeding $\gamma = 0.3x10^{20}$ A/Wm^{-2} have been obtained. In ITER, LH is predicted to retain the highest efficiency for off-axis current drive (r/a ³ 0.5).

Recent experiments have demonstrated the efficiency of LH H&CD in creating and maintaining reversed shear configurations (FT-U, JET, JT-60U, Tore Supra), in establishing a local transport barrier, and in achieving an improved global confinement. Thermal barriers established in this way have displayed the same enhanced performances when strong central plasma heating was subsequently applied as those prepared by fast ramp-up or early NBI heating.

However, LH waves can not penetrate to the centre of a nominal ITER plasma (the accessibility limit being $n_eT_e \approx (10\text{-}15) keVx10^{20}m^{-3}$). Therefore it cannot be considered a principal ITER plasma heating method.

The Lower Hybrid System is composed of two launcher plugs installed in two equatorial ports each consisting of two sections, one in the vacuum vessel (antenna plug) and the other in the cryostat interspace (secondary plug). The antenna plug design is based on the concept of Passive-Active Multijunctions (PAM) wave guide array. Four PAMs are used for each antenna. A PAM module is constructed by stacking thick copper plates terminated at the plasma end by a short Be groove acting as a short circuited passive wave guide. The gaps between adjacent plates constitute the active wave guides. The array $N_{//}$ spectrum is fixed at $N_{//} = 2$ with a directivity better than 70%. The operating power density of the antenna plug is about 23 MW/m^2, corresponding to an electric field inside the active wave guide of 2.8 kV/cm.

Each PAM is connected through an oversized wave guide section (Hyperguide) to 24 $TE_{01\text{-}03}$ mode converters. A transmission efficiency better than 98% is achieved for a converter length of 0.5 m. Two mode converters are connected through a 3 dB hybrid junction to one rectangular Vacuum Transmission Line (VTL) located in the secondary plug.

Each antenna is fed by 8 oversized (C10) circular waveguides operating in the TE_{01} mode (Main Transmission Lines), connected to a 1-to-6 splitting network at the launcher end, and to a recombining network at the generators end, to combine the power of 4 klystrons.

TECHNOLOGY

Electron Cyclotron feasibility relies heavily on the successful development of gyrotron and window technology. The EDA goal is the demonstration of a 170 GHz, CW, ~50% efficient, 1 MW gyrotron together with suitable windows for use on the torus and tube. Great progress towards the major goals has been achieved, albeit not simultaneously in a single tube:

- 1.75 MJ at 170 GHz in long pulse (10 s) operation;
- 3.1 MJ at 170 GHz in high power operation (6.20 s at 500 kW);

- Demonstration of depressed collector operation at 110, 140, and 170 GHz with efficiencies up to 50%;
- Demonstration of 1 MW output at up to 2 s at 110 and 140 GHz.

Another major success has been the rapid development of a water cooled, single disk diamond window. Within a two year period, the technology to manufacture large diameter diamond disks has been developed, with such improved material quality that 2 MW CW windows are theoretically feasible. The technique to bond dielectric to metal tubes has also been developed, a complete window assembly has been fabricated and is currently installed and undergoing tests on a tube.

Ion Cyclotron relies on a more mature technology requiring, however, upgraded performance in transmission and power generation equipment. EDA R&D development is focused on the validation of the IC array design and on the development of prototypes for the most critical components. These include i) the vacuum pre-tuners, ii) the vacuum transmission line all metal supports, which avoid the use of ceramic materials within the ITER primary vacuum and iii) the (dielectric) vacuum window, complying with the stringent reliability requirements of ITER vacuum and tritium boundaries. A full-size, single strap prototype antenna is being developed for validation of the array design, to be optimised and tested at full design voltage (50kV) in vacuum.

ITER relevant Lower Hybrid technology developments have been performed within the frame of the European base program and focus on the development of the LH array components. The operation of the multi-mode hyperguide section and of the associated $TE_{01,03}$ converters have been demonstrated at 3.7 GHz and the electrical performance of a full size model of a PAM assembly has been experimentally evaluated in vacuum tests. Plans are presently made for the installation of a prototype section of the ITER PAM array in Tore Supra, for intensive tests in long pulse operation.

CONCLUSIONS

Three Heating and Current Drive RF Systems have been developed during the EDA to demonstrate their basis for adoption in ITER. The designs are sufficiently developed to allow an assessment of feasibility, to identify issues, and to examine solutions for specific problems. The associated R&D program has focused on the development of the technology of basic components, when still not available, and on the validation of design concepts. The three systems are able to fulfil ITER operational requirements and offer prospects for an efficient and reliable operation.

Items to be considered for inclusion in the ITER Newsletter should be submitted to B. Kouvchinnikov, ITER Office, IAEA, Wagramerstrasse 5, P.O. Box 100, A-1400 Vienna, Austria, or Facsimile: +43 1 237762, or e-mail: c.basaldella@iaea.org (phone +43 1 206026392).

Printed by the IAEA in Austria
July 1998

98-02352