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DEVELOPMENTS IN ITER PHYSICS R&D

by Dr R.Aymar, ITER Director

Physics work in the base experimental and theoretical research programmes of the ITER Parties is a crucial part of the validating research and development required for ITER. The projections of ITER performances require extrapolations from present experience and these must rest on established theory and experimental results from the leading laboratories, facilities and universities that together pursue the Parties' fusion science programmes.

The Parties undertake their Physics work for ITER on a voluntary basis outside of the framework of task assignments established for ITER Tasks in technology R&D and Design. Nonetheless the Parties' various efforts are undertaken in a structure designed to offer coherence and co-ordination of the voluntary contributions. An ITER Physics Committee comprising the Director and the Parties' designated persons for ITER Physics exercises oversight and is supported by seven Physics Expert Groups (see the article on ITER Physics R&D, IAEA EDA Newsletter Vol. 3, No. 9, and sections on physics progress in the Director's status reports).

With the wholehearted support and commitment of individuals and organizations throughout the Parties, this structure has proved to be extremely effective in providing the necessary physics support to the ITER design activities, the results of which are in process of publication as "The ITER Physics Basis" in a special edition of the journal Nuclear Fusion (December 1999), published by the IAEA. At the same time, ITER has proved a catalyst to general progress in tokamak Physics through the discipline and focus required to identify and address efficiently the main challenges of establishing the ITER Physics Basis.

At their last meeting, the Physics Committee discussed the future of the ITER Physics Expert Groups and affirmed the importance of the activities in providing and improving the physics basis for the design effort aimed at options for cost reduction. The Committee concluded that, whilst the present structure of seven Expert Groups should remain, the groups should be restructured to allow for realigned and expanded disciplinary responsibilities, as follows (summary information about the areas of activity for the Expert Groups is shown in Table 1 overleaf):

- The former Divertor Physics Expert Group has been renamed the Edge and Pedestal Physics Expert Group and is responsible for edge-region physics and databases of plasma parameters inside the separatrix. Co-ordination with the H-mode power threshold database must be worked out.
- The former Divertor Modeling and Database Expert Group has been renamed the Scrape-Off-Layer and Divertor Physics Expert Group and has responsibility for physics and databases of plasma at the separatrix and in the SOL and divertor chamber.
- The Energetic Particles, Heating, and Steady-State Expert Group now has responsibility for integrated steady-state physics, not just current drive methods.
- The Transport and Internal Barrier Physics Expert Group has as its responsibility the physics of core transport and its control by internal or H-mode barriers. Transport of heat, particles, and angular momentum are all important.
- Activities of the Confinement Database and Modeling Expert Group are extended to include advanced/Internal Transport Barrier operations as well as nominal ELMy H-mode scenarios.
- Single-subject Topical Working Groups were endorsed as a needed mechanism to effect cross-Group communications on plasma behaviour that impact on more than one Group's responsibilities. Topical Working

Groups do not hold separate meetings, but meet instead as co-ordinated extensions of planned Expert Group meetings. As a result, Expert Group meetings can no longer be independently scheduled but must be planned in a co-ordinated way.

- All Expert Group meetings are to be scheduled in a co-ordinated way that will permit appropriate joint sessions and Topical Working Group meetings to occur.
- Expert Groups are limited to two meetings per year, one normally in conjunction with a scheduled scientific meeting.
- An ITER Database Standards Committee will be formed. The Database Standards Committee will develop standards for existing and proposed ITER database activities and conduct annual reviews to assure that standards are met. The Committee will consist of Expert Group Co-Chairs plus a Committee Chair to be named by the Director.

Table 1 - EXPERT GROUP STRUCTURE 1999

Expert Group	Area of Activity
Diagnostics	Physics of plasma measurements and principles of their integration into the design relative to anticipated requirements
Edge and Pedestal Physics	Physics processes in the edge plasma inside the separatrix. H-mode transition physics. Transport and ELMs in the barrier region.
MHD, Disruptions, and Control	Global plasma process and their consequences, MHD instabilities, physics of ELMS, operational limits, and their associated design requirements. Control methods to improve plasma performance.
Energetic Particles, Heating, and Steady-State Operation	Effects of energetic particles created by auxiliary power sources or thermonuclear reactions on the evolution and stability of plasma processes. Auxiliary power methods to create energetic particles, plasma heating, current drive, and rotation. Profile control for Steady-State operations.
Scrape-off-layer and Divertor Physics	Plasma physics and plasma-material interactions in the scrape-off-layer plasma. Control of heat flux onto material surfaces as well as control of particle inventory by pumping.
Transport and Internal Barrier Physics	Core turbulent transport of heat, particles and angular momentum and its control as exemplified by internal and H-mode transport barrier (theory and experiment).
Confinement Database and Modelling	Assembly of global and profile databases for nominal ELMy H-mode operations as well as advanced/ITB scenarios. Development, archiving, and testing of empirical and first-principles transport models for these scenarios.

Summary information about the urgent priority areas for Physics as identified by the Physics Committee are shown in Table 2 on page 3.

Following the Parties' endorsement of these developments, and subsequent consultations with the Parties through the Designated persons, the Chairs, Co-Chairs and members of the Expert Groups under the new structure have been determined. (See Table 3 at the end of the article.)

Since the planned staff of the ITER Physics JCT members will be insufficient to carry out needed Expert Group Co-Chair activities, some Parties are providing co-chairs who will be able to spend some time (~2 months/year) working with the Physics Integration Unit at the Joint Work Sites. In addition to the designated members, there is the possibility for the Expert Groups also to draw on a wider pool of people able to assist in specific areas.

Table 2 - 1999 URGENT PHYSICS RESEARCH AREAS

Research Area	Issues	Resources	Impact
Plasma Termination and Halo Current	Halo- and eddy-current **jxB** forces on structural components Runaway electron currents Disruption mitigation Thermal quench charac-ter-ization	Additional halo current data from tokamaks; disruption thermal quench database 3D resistive MHD codes with runaways Effects of massive deuterium injection Killer pellet experiments	Provides better estimate for **JxB** forces on first wall, vacuum vessel Demonstrates plasma termination method Provides for experimental validation of runaway electron current evolution
Divertor Detachment and Radiation Loss Physics	Effect of divertor detachment on confinement SOL plasmas and impurity flows Divertor geometry effects Divertor scalar, ELM, and edge/pedestal databases SOL cross-field transport scaling	Well-diagnosed divertor experiments with various degrees of baffling and controlled impurity injection Computing time and facilities to obtain good throughput Systematic collection of SOL, ELM, and pedestal data; especially for ITER Demonstration Discharges	Demonstrates consistency between radiating sufficient power and main-taining H-mode confine-ment Predictive divertor design capability Provides database of edge, pedestal, and SOL plasmas parameters for Divertor, H-mode thres-hold, and boundary con-dition for local transport modelling
Density Limit Physics	Physics of edge density limit, especially for H-mode plasmas. Role of H => L transition Improvements in fuelling efficiency resulting from inside pellet fuelling. Retention of pellet material	Experiments with various degrees of baffling and triangularity at separatrix. Inside pellet launch capability	Determines scaling of edge density limit for H-mode plasmas
Finite-b effects	ITER Demonstration Discharges; role of rotation Stabilization of neoclassical islands Tolerable ELMs Role of wall stabilization	ITER Demonstration Discharges Modulated ECCD sources and modelling capabilities High time and spatial resolution of T_e, n_e profiles during ELMs. ICRF vs. NBI ELMS; High triangularity and ELMs Active n=1 coils	Identifies principal b-limiting mechanism (neo-classical islands or ELMs?) Specifies ECH power, launch angle and position for feedback stabiliation Characterizes ELMs vs δ Determines steady-state β-limit
H-mode power threshold and pedestal physics	H-mode accessibility in RC/ITER. Data scatter Scaling of pedestal pro-per-ties and ELMs Effect of plasma shape on pedestal and ELMs	Coordinated experiments. Data scatter reduction Non-dimensionally identical H-mode transitions Pedestal Database	Validates whether H-mode confinement can be attain-ed in ITER Elucidates scaling trends of edge T_e, n_e at transition

to be continued on the next page

Research Area	Issues	Resources	Impact
Core confine-ment. ELMy H-mode and Ri mode	Non-dimensional scaling experiments; effect of finite b and flow shear. Confinement scaling near operational limits Development of 1.5 D local transport models; profile database Ri mode in large divertor tokamak	Non-dimensional scans to establish scaling trends Ascertain importance of flow shear via NBI vs. ICRF comparison HFS pellet launch Impurity injection to estab-lish RI mode Profile database for testing local transport models	Data to validate methodolo-gy for projecting core con-fiement to an ITER-scale device Establishment of common physics gives confidence in scaling Selects models that can replicate present data
Internal Transport Barrier Properties	Can Internal Transport Barriers with $T_e \approx T_i$ be formed and endure? Scaling and optimization of ITB properties; ITB power thresholds Helium exhaust and core fuelling	Inductively-formed, re-verse-shear Demonstration Discharges Variety of auxiliary heating methods; increasing ECH capabilities Helium injection methods	Reliable ITBs will bring RC/ITER to ignition Accessibility of ITB regime in RC/ITER determined
Scenarios for Steady-State	Are n=l active control coils needed for reactor b-values (β>0.03) in steady-state? Will a conducting wall and rotation assure stability against n=1 modes un-sta-ble "with a wall at in-finity"? Will the resistive wall mode stop plasma rotation?	Active n=1 feedback coils Auxiliary-power current drive capabilitiesLinear sta-bility codes Modelling codes to explore the self-consistency of var-ious profiles Plasma discharges in wall-stabilized regime	Determines operational β-limit for high-bootstrap frac-tion discharges Provides basis for project-ing whether RC/ITER will exceed Q≈5 in steady-state Determines stable boot-strap and driven current density profiles
Plasma-wall inter-action	Will erosion and material transport limit the lifetime of divertor hardware? Model development Tritium codeposition, reten-tion, and recovery Wall conditioning tech-niques	Analysis of TFTR and JET first wall material and tritium retention Impurity and fuel (DT) gas injection Erosion diagnostics such as DIMES ECH discharge cleaning with and without oxygen	Guides selection of diver-tor plasma-facing material Provides data to estimate tritium retention inventory versus safety limit

Dr. Shimomura, the Deputy to the Director has accepted the responsibility for co-ordinating the schedule of the Expert Groups.

Given the continued commitment, support and recognition of their value, the ITER Physics Expert Groups will, it is hoped, continue to make the profound impact on the world-wide progress of tokamak physics, to the benefit both of ITER and of fusion science in general.

Following the US withdrawal from the ITER EDA Agreement, US physicists no longer participate in the ITER physics activities. However, it is expected that mutually beneficial interactions with the US fusion physics community will continue outside of the ITER framework on the underlying general issues of tokamak physics that relate to the ITER-specific work of the Expert Groups.

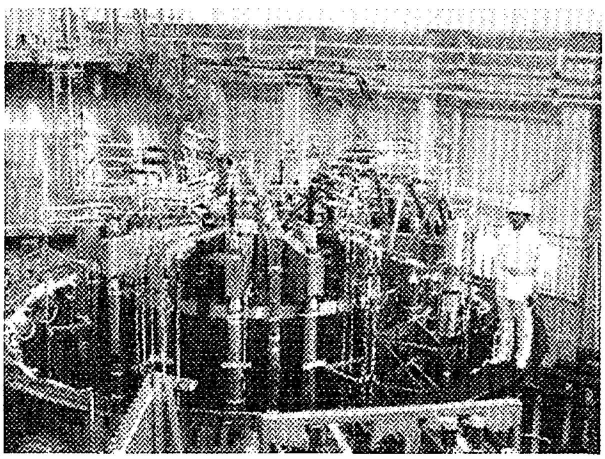
Table 3 - ITER PHYSICS EXPERT GROUPS (1999-2001)

	Chair	Co-Chair	EU	JA	RF
Physics Committee	ITER Director	M. Shimada			
Designated Persons			D. Campbell	M. Wakatani H. Ninomiya	N. Ivanov
Senior Physicists			M. Keilhacker C. Lackner	T. Tamano R. Yoshino	Y. Dnestrovski S. Mirnov
Diagnostics	A.J.Donne	A. Costley	F. Orsitto P.E. Stott	H. Zushi Y. Kusama T. Sugie	V. Strelkov A. Kisliakov A. Krasilnikov
Scrape-off-layer and Divertor Physics	N. Asakura	A. Loarte	G. Matthews J. Neuhauser V. Phillips Ph. Gendrih	T. Kato S. Takamura A. Sakasai	V. Pistunovich
Edge and Pedestal Physics	Y. Kamada	G. Janeschitz	L. Horton W. Suttrop H. Weisen	N. Ohyabu T. Hatae	V. Osipenko
MHD, Disruption and Control	O. Gruber	Y. Gribov	O. Gruber T. Hender J. Lister	S. Tsuji-Iio T. Ozeki R. Yoshino	V. Lukash S. Mirnov N. Ivanov
Energetic Particles, Heating and Steady State Operation	C. Gormezano	K. Miyamoto	A. Becoulet A. Jaun	A. Fukuyama Y. Takase K. Tobita S. Ide	K. Razumova V. Vdovin S. Konovalov
Transport and Internal Barrier Physics	M. Wakatani	V. Mukhovatov	X. Garbet F. Soldner J. Connor	K. Toi T. Fukuda	Y. Esipchuk V. Vershkov S. Lebedev
Confinement, Database and Modelling	G. Cordey	V. Mukhovatov (interim)	F. Ryter J. Connor	T. Takizuka Y. Ogawa Y. Miura	A. Chudnovski V. Leonov

Physics Committee Members are shown in the fields with grey shadow

COMPLETION OF THE ITER CENTRAL SOLENOID MODEL COILS INSTALLATION

by Dr. H. Tsuji, Head, Superconducting Magnet Laboratory, JAERI, Naka



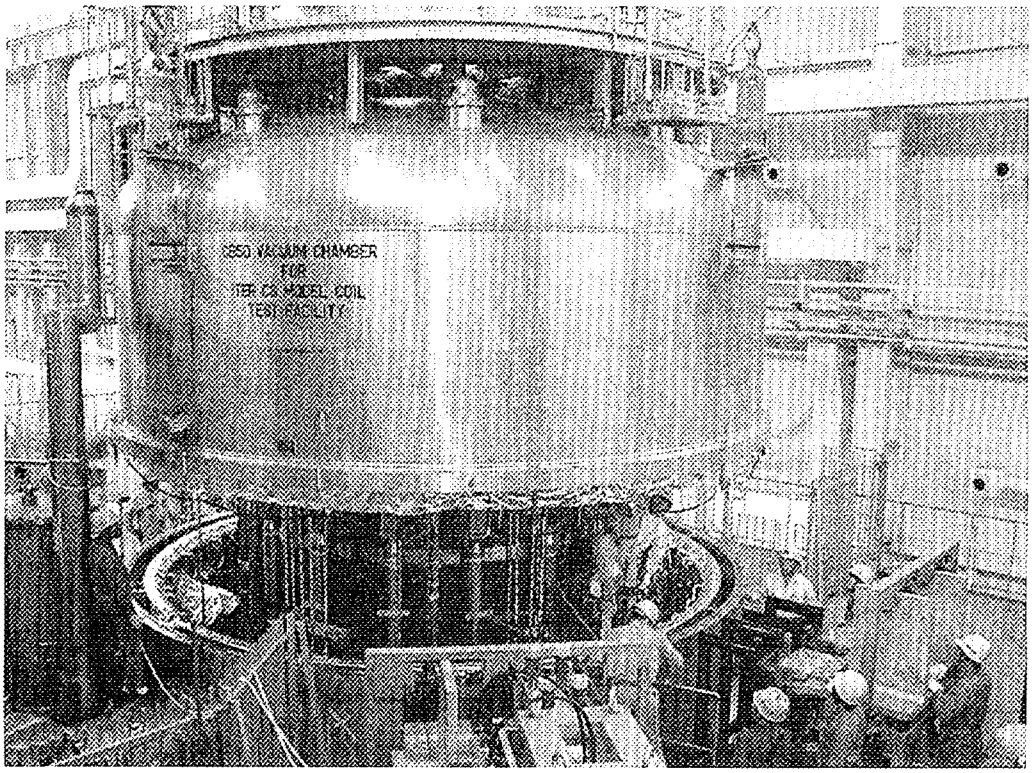
The CS Model Coil and CS Insert Coil after the completion

From June 2, 1999, after the ceremony held on the successful fabrication of the Central Solenoid (CS) Model Coils the day before, installation of the ITER CS Model Coil Inner Module, CS Model Coil Outer Module and the CS Insert Coil has been carried out by the US Installation Team, headed by R. Vieira, the JA Installation Team, headed by T. Kato, and the Toshiba Installation Team, headed by S. Ikeda, working in close collaboration under the supervision of the JCT Team, headed by

During the installation of the three Nb3Sn superconducting coils into the vacuum tank, dozens of problems were faced and successfully overcome one by one at JAERI-Naka.

128 days had passed after the first tension rod was installed on 2 June, till installation work was completed and the vacuum tank was closed on 7 October 1999, at 11:45 a.m.

The total winding weight of the coils now in the tank is 110 tons and the total weight to be cooled down to 4K is 180 tons. The outer diameter of the winding is 3.6 m being similar to that of the CS of the reduced size ITER. The number of pipe weldings was 895, and about 550 sensors were also installed to monitor the performance of the coils.



The upper lid of the vacuum tank has been slowly brought down. K. Kawano, a staff member of the JAERI superconducting magnet laboratory, is still inside the tank, carefully watching the closure of the vacuum tank to prevent any damage to the coil system.

On October 14, 1999, the CSMC and CSIC system passed the High-Potential Test with the following results:

The CS Model Coil (Inner Module and Outer Module) System: applied voltage = 20.7 kV, duration = 10 minutes, leak current = 125 micro-ampere

The CS Insert Coil System: applied voltage = 20.7 kV, duration = 10 minutes, leak current = 20 micro-ampere

The vacuum pumping is scheduled to start on October 18, 1999.

After the vacuum pumping down and the final helium leak test, the cooling down of the coils is expected to start in November 1999. Four weeks will be necessary to bring the three coils down to 4K.

Items to be considered for inclusion in the ITER Newsletter should be submitted to B. Kouvchinnikov, ITER Office, IAEA, Wagramer .Strasse 5, P.O. Box 100, A-1400 Vienna, Austria, or Facsimile: +43 1 2633832, or e-mail: c.basaldella@iaea.org (phone +43 1 260026392).

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